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AN IMPROVED X-RAY DIFFRACTION CAMERA

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For obtaining high quality X-ray diffraction patterns with minimum exposure times, an improved Debye-Scherrer camera has been designed and is produced by North American Philips Co., Inc. Various factors entering the design of the camera and interrelated in their influence on the properties of the patterns are considered in this article. The necessary compromises between such properties as line intensity, line sharpness (resolution), contrast and line shape are favorably affected by several resources. Line intensity is improved without loss of resolution by using a rectangular collimating aperture for the X-ray beam. Contrast is enhanced by surrounding the primary beam on its path to and from the specimen by a collimator and exit tube, thus diminishing the film blackening resulting from radiation scattered in the air. It is shown that these "anti-air-scatter tubes" must have definite dimensions in order to insure the limitation of air scatter to a minimum without causing undesirable blind areas in the diffraction patterns and avoiding any scattering from the tubes themselves. The optimum forms of the tubes for different purposes have been computed, and the cameras can be provided with one of several systems designed in accordance with the results of these computations. The tubes are made easily interchangeable. Handling of the cameras in general is simplified to a considerable extent by the application of certain mechanical design principles outlined by Buerger.

In this article a description is given of an improved camera for the photographic recording of X-ray diffraction patterns of polycrystalline (e.g. powder) specimens according to the Debye-Scherrer method. There is no need to enumerate here the many purposes which these patterns may serve. It is sufficient to state that they are used extensively in research and industrial laboratories for the identification or chemical analysis of materials, for the examination of crystalline structure and grain size, and for the analysis of stresses, texture etc. [1]).

Fig. 1 illustrates the well-known principle of the Debye-Scherrer camera. This camera is a cylindrical enclosure along the axis of which the cylindrical specimen is mounted; the film strip is placed against the inner wall of the camera. The X-ray beam (made as monochromatic as practicable) enters the camera through an aperture in the cylindrical wall. Parts of this beam are diffracted at definite angles by the tiny crystals in the specimen and produce characteristic diffraction lines on the film, while the diffracted part of the (primary) beam passes on to a stop or receiver, or may leave the camera through an aperture in the opposite cylindrical wall.

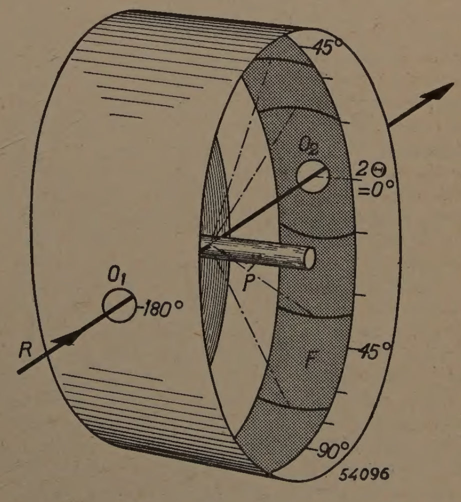

Fig. 1. Principle of the Debye-Scherrer camera. A monochromatic X-ray beam R enters the cylindrical camera through an aperture O_1 and is partly diffracted in the specimen P. The undiffracted part of the beam leaves the camera through the aperture O_2. The diffracted rays cause the lines (ring segments) of the diffraction pattern on the film F.

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[1]) A survey of the applications of the Debye-Scherrer method can be found, for instance, in Philips Techn. Rev. 5, 157-166, 1940. A few months ago an article in this Review was devoted to the "Geiger counter X-ray spectrometer", an apparatus also produced by North American Philips Co., Inc., and enabling the direct measurement of the intensity distribution of X-ray diffraction patterns (Philips Techn Rev. **10**, 1-12, 1948 (No.1)). The Geiger counter method and the photographic method are well suited to supplement each other due to their different performance characteristics.

A well designed Debye-Scherrer camera should meet the requirements that, on the one hand, the recording of a pattern be made as easy and quick as possible, while, on the other hand, the highest possible quality of the resulting patterns be secured.

As far as ease of handling is concerned, the cameras produced by North American Philips Co., Inc., have been designed in the main in accordance with the cameras described a few years ago by M. J. Buerger [2]). The principles outlined by Buerger were aimed, among other things, at facilitating the alignment of the camera with the X-ray tube, the recovering of the alignment after temporary removal of the camera from its position, the centering of the specimen in the camera, the rapid mounting of the film, etc. The successful realization of such principles depends mainly on precise mechanical construction. Those are not the subjects which are extensively treated in this article, although some details relating to the aforementioned principles are given in *figs 2* and *3* and explained in the accompanying legends. On the contrary, this article deals much more thoroughly with the speed of recording and the quality of the patterns obtained.

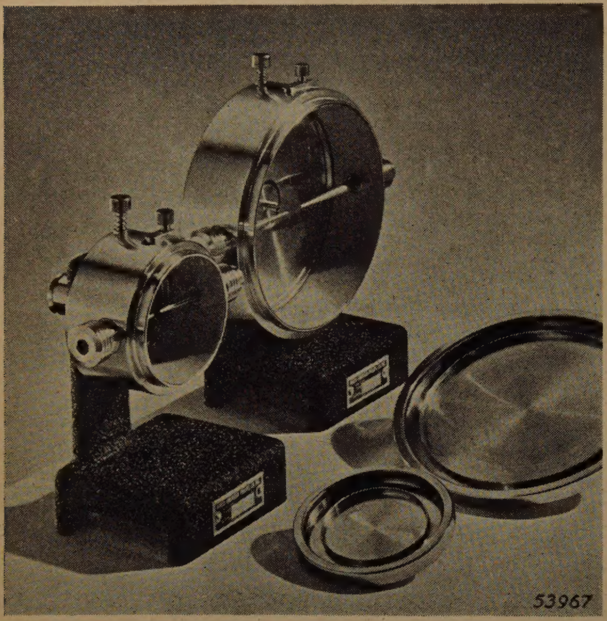

Fig. 2. The Debye-Scherrer cameras with diameters of 57.3 and 114.6 mm, as manufactured by North American Philips Co., Inc. Next to the cameras are the covers, fitting light-tight on the cameras, so that it is not necessary to make exposures in a dark room nor to cover the film with black paper. In each of these cameras the primary X-ray beam passes through two conical tubes between which the very thin rod-shaped specimen is mounted. After placing the specimen roughly on the axis of the camera it is accurately centered by means of a threaded "pusher" perpendicular to the axis. This is facilitated by slipping a small magnifying glass on the end of the exit tube. During the exposure the glass is replaced by a cap containing a small fluorescent screen, on which the primary beam and the shadow of the specimen may be observed. Thus the alignment of the camera and the centering of the specimen are checked. The fluorescent screen is covered at the inside with black paper, making the camera light-tight, and at the outside with lead glass, absorbing the remainder of the primary beam without obstructing the view of the fluorescent screen. The film is placed in the camera according to the Straumanis method: the film takes up nearly 360°, and two holes of normalized width of 9 mm are punched in it where the tubes are to be inserted. Careful design and machining of the tubes make it possible to remove them easily for mounting the film and to replace them in exactly the correct alignment. The film is expanded tightly against the inner wall of the camera by means of a movable finger which pushes one end of the film, the other end being fixed by a stop.

Properties involved in quality of pattern

Information about the nature of the X-rayed specimen can be deduced from the positions (i.e., the diffraction angles) of the diffraction lines, from their relative intensities and from the line shape. High quality patterns, therefore, will exhibit the following properties:

1) Recording of all lines that are of importance. This especially refers to very weak lines, which may often be important in quantitative chemical analysis by X-ray diffraction, and to lines at very small or very large diffraction angles (2Θ near zero or 180°, Θ = Bragg angle).
2) Great sharpness of lines. This will enable the diffraction angles to be determined very accurately and at the same time it will provide a good resolution of adjacent lines.
3) Good contrast of recorded picture, i.e., minimum and relatively uniform background density on the film in comparison to the density of the lines. A strong background would not only affect the observable recording of very weak lines mentioned in (1), but also impair the measurement of the correct relative intensities, for strong as well as for weak lines.
4) Good line shape, i.e., correct contour, uniform density, and constant intensity along the usable length of each line (insofar as the desired data do not actually depend on broadening, spottiness or specific intensity distribution of each line). This property is important for good definition of the position of the lines and for correct intensity measurements.

   In order to meet the requirement of quick recording of patterns, especially in view of point (1), we must add to this list of desiderata:
5) High intensity of diffracted rays.

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[2]) M. J. Buerger, The design of X-ray powder cameras, J. Appl. Phys. 16, 501-510, 1945. Cf. also: M. J. Buerger, An X-ray powder camera, Amer. Mineralogist 21, 11-17, 1936.

Camera design considerations relating to quality of pattern and speed of recording

When considering the design factors which influence the abovementioned properties it becomes apparent that in several instances the requirements are conflicting. For the sake of convenience let us start from the sharpness of lines.

Sharp definition of the lines mainly depends on the diameter of the camera, the width and divergence of the primary X-ray beam, and the thickness of the specimen.

Simple geometrical considerations show that the lines become sharper (i.e. narrower in relation to their mutual separation distances) with an increase

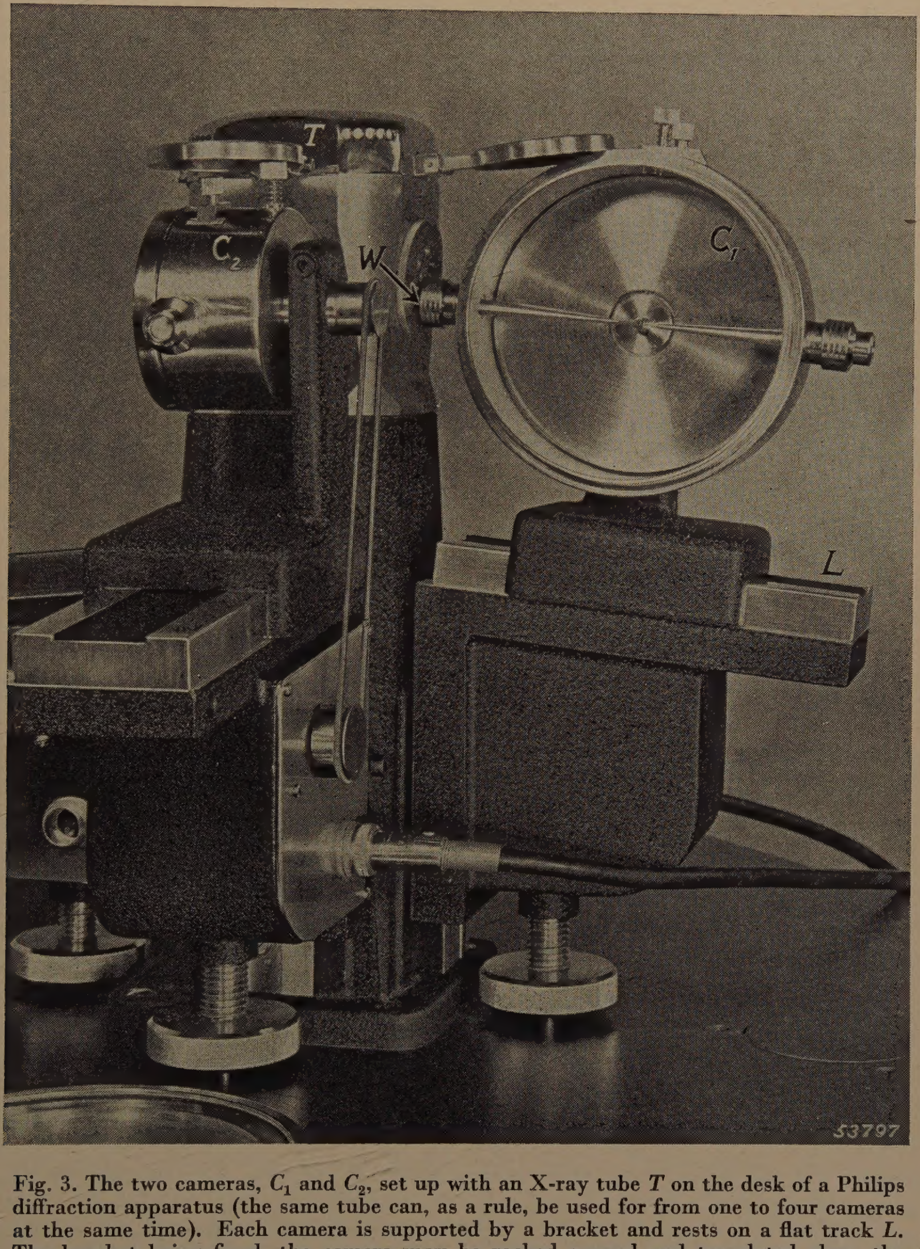

Fig. 3. The two cameras, C_1 and C_2, set up with an X-ray tube T on the desk of a Philips diffraction apparatus (the same tube can, as a rule, be used for from one to four cameras at the same time). Each camera is supported by a bracket and rests on a flat track L. The bracket being fixed, the camera may be rocked around and translated along the specimen axis; the track may be translated along and rocked about a vertical axis (parallel to the X-ray tube housing). This permits an easy aligment of the diffraction camera with the corresponding exit window (W) of the X-ray tube. Once aligned, the camera may be removed for film processing and reloading, and repositioned on the track without need for further alignment. Small and large cameras may be interchanged without altering the position of the track. The X-ray tube, too, is designed to allow changing tubes (e.g., for varying the target material) without affecting camera aligment. The tracks make an angle of 6° with the horizontal plane. Hence, if the camera is rocked around its axis so that the two tubes are parallel to the track, the X-ray beam used makes an angle of 6° with the horizontal face of the X-ray tube target. By slightly rocking the camera and raising the track this angle can be made smaller (e.g., 3°). While the exposure is being made the specimen is rotated continuously around its axis by a pulley attached to a small electric motor covered under the track.

in the diameter of the camera. Enlarging the camera, however, is soon limited by the rapid decrease in line intensity. In order to keep the exposure times within reasonable limits, one does not go any further, as a rule, with the camera type under consideration, than the frequently used 114.59 mm diameter. The Philips cameras possess diameters of 114.59 and 57.3 mm ³).

Next, consider the divergence of the irradiating X-ray beam. Lines will be sharper for a smaller beam divergence, as may be seen from *fig. 4*. On the other hand, a larger area of the X-ray tube focus contributing to the irradiating energy corresponds with a greater divergence of the beam (the distance between focus and specimen, and the angle at which the anode surface is viewed being given). Hence, a compromise between line sharpness and line intensity again will be necessary.

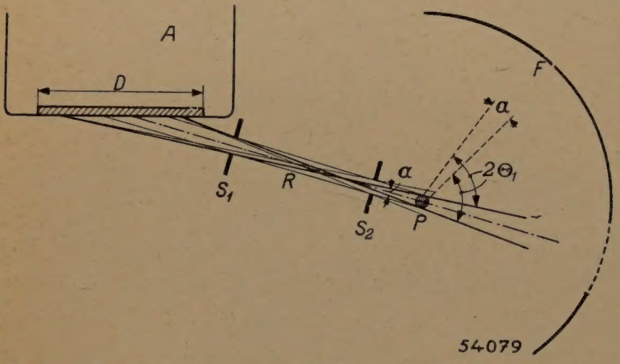

Fig. 4. Vertical cross-section of the cylindrical camera (not drawn to scale), showing film F, specimen P, anode A, focal spot D and beam collimating apertures S_1 and S_2. The divergence of the primary X-ray beam R (in this case limited by aperture S_1 and specimen diameter) is α. The same angular divergence appears between rays diffracted at the outermost points of the specimen cross-section and contributing to one diffraction line ($2\Theta_1$ = diffraction angle).

Finally the thickness of the specimen (which also determines the necessary width of the primary beam) should be considered. To obtain sufficiently sharp lines, the specimen must be extremely thin, in some instances 0.3 mm or even less. Evidently the X-ray energy diffracted by the specimen will, then, be very small. So we have once again the conflict between line sharpness and line intensity. In this case, however, other requirements mentioned above are involved in the conflict too. Diminishing the specimen diameter is apt to create a very unfavorable condition with respect to the contrast of the pattern and the line shape. This may be seen in the following way:

The main cause of the occurrence of a uniform background on the film, detrimental to contrast, is the scattering of the primary beam in the air through which it passes on its way through the camera ⁴). Given a certain path length of the beam in air and assuming the beam width in all cases to be equal to the thickness of the specimen, the air volume contributing to the undesired scattering will decrease proportionately to this thickness. The volume of the specimen contributing to the desired diffraction, however, decreases according to the square of the specimen thickness, so that the air scatter will be relatively more pronounced the thinner the specimen.

Similarly, the unfavorable effect on the line shape may be understood. Given the average size of the crystals oriented at random in the specimen, the number of crystals irradiated decreases with the square of the specimen thickness, and so does the average number of spots from which each diffraction line is built up, while the line width on which the spots are distributed diminishes only proportionately to this thickness. Thus, the lines in the diffraction pattern will be less uniformly blackened and, in the extreme case, tend to get a spotty appearance on decreasing the specimen diameter. (This is quite noticeable in the examination of compounds of low crystal symmetry, for which a given type of lattice planes will attain an orientation suitable for reflecting only in a single or very few positions of the crystal.)

The various conflicts pointed out to exist between desired features and necessitating as many compromises in camera design, may have caused a somewhat gloomy impression as to camera performances which can be expected. Fortunately, there are several resources which favorably affect the necessary compromises and which have been applied in the Philips cameras with considerable success. One such resource, well-known for a long time, is the rotating of the specimen during the exposure (combined with a translation along its axis if desired); cf. fig. 3. This results in more crystals

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³) These seemingly odd diameter values have the advantage that the diffraction angles 2Θ are in a simple way numerically related to the line distances measured in mm on the film: 1° of 2Θ corresponds to 1 mm with the 114.59 mm camera, to $^1/_2$ mm with the 57.3 mm camera.

⁴) We will not consider in this article causes such as possible fluorescence (X-rays or light) which is brought about by the primary beam in the specimen and which is non-directional, or the "white" (non-monochromatic) components of the X-ray beam which produce a diffraction spectrum for every wavelength that is present, all these spectra being superimposed to form a continuous background. These contributions to background (and hence indirectly also the contribution from air scatter) may be diminished by special measures for making the primary beam more monochromatic, e.g. by means of a "crystal monochromator". Such a device may also be used with the Philips cameras. The scattering of the beam at various apertures through which it passes will be discussed below.

coming temporarily in an appropriate position for contributing to a specific diffraction line and, hence, in diminishing the spottiness of lines. Other resources, also well-known but, in our case, applied in a novel manner, are concerned with the X-ray beam geometry and the reduction of air scatter. These will be treated to somewhat greater detail in the following parts of this article.

Geometry of beam collimating system

The desired beam shape is obtained by means of a collimator system, commonly consisting of two pinhole apertures (cf. fig. 4). When diminishing the specimen thickness to values of, say, 0.5 or 0.3 mm, the width of the X-ray beam had to be adapted to the specimen thickness by making the collimator apertures narrower. This was necessary, because all parts of the primary beam failing to strike the specimen do not add to the line intensity but only to the undesired air scatter. This necessity, however, applies only to the width of the beam in the "equatorial" cross-section of the camera and the specimen, represented in fig. 4. The width of the beam in a direction parallel to the specimen axis, need not be limited to the same content. This means that the beam need not be made rotation-symmetrical but that it can be given an oblong cross-section, by taking a rectangular slit rather than a circular pinhole as a first collimator aperture; cf. *fig. 5*. The obvious advantage of this is that a relatively long part of the rod-shaped specimen is irradiated, resulting in a higher intensity of the diffraction lines and, at the same time, in a more uniform blackening of the lines and truer relative intensities because a larger number of crystallites are irradiated [5]).

A limit to the slit length is set by the fact that with too great a divergence of the X-ray beam in a direction parallel to the specimen axis, the line sharpness and line shape will again begin to suffer. This is explained with reference to *fig. 6*. An ideal diffraction line is the intersection of the film with a cone of rays the apex of which lies in the specimen and the axis of which is the direction of the primary ray. With a diverging primary beam each ray will produce its separate diffraction cone. Each diffraction "line", then, is formed by the superposition of a continuous series of cones with different axes. This results in a broom-shaped broadening of each line on either side of the "equator" of the film, and in the case of a strongly diverging primary beam it also results in a line broadening at the equator itself. The effect is very noticeable at very small and large diffraction angles where the arcs form complete circles.

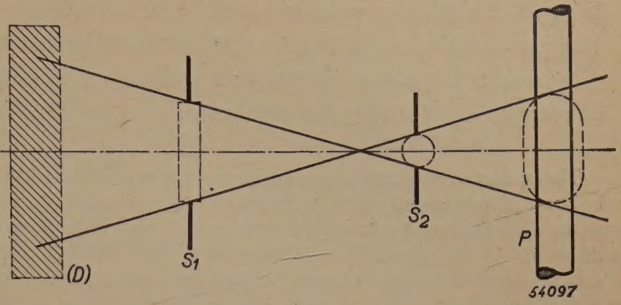

Fig. 5. Horizontal section of the primary X-ray beam. The first collimator aperture S_1 is made rectangular; S_2 is the circular second aperture; P, the specimen; D, projected focal spot. At P the X-ray beam has an oblong cross-section. (The cross-sections of D and of the beam at S_1, S_2 and P are turned in the plane of the drawing and indicated by dotted lines.)

This well-known "slit effect" is not troublesome with the aperture dimensions chosen for our cameras. The first aperture is 0.5 mm wide and 2 mm long, the second one is circular, with a diameter of, say, 0.5 mm. The resolving power for adjacent lines proves to be hardly less than that of the usual systems with two circular pinhole apertures of 0.5 mm diameter, and it is certainly better than

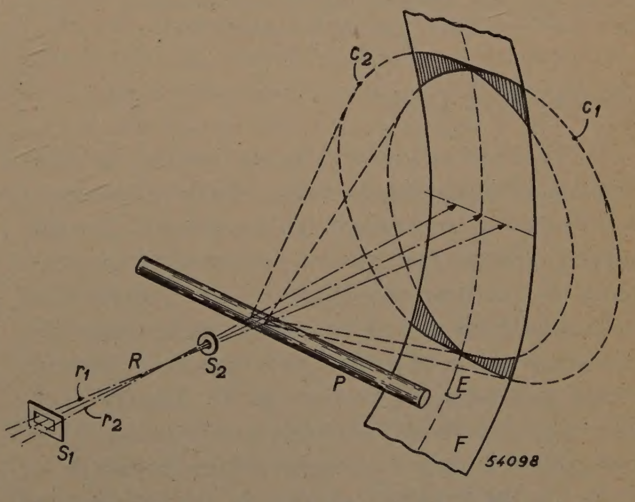

Fig. 6. Slit effect on shape of diffraction lines. Diverging rays of the primary X-ray beam R produce different cones of diffracted rays, each having its original ray as an axis. Diffraction lines on the film are obtained by the superposition of eccentric rings arising from the intersection of such cones with the film. c_1 and c_2 are the rings produced on the (virtually extended) film surface by the rays r_1 and r_2 respectively; E is the "equator" of the film F.

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[5]) On the use of a rectangular first collimating aperture see e.g. F. Halla and H. Mark, Röntgenographische Untersuchung von Kristallen, Leipzig 1937, p. 156. The successful application of this device depends on extreme precision in the mechanical construction and particularly in the alignment of the slit with the focus and the specimen. Special precision techniques and tools have been developed for this purpose in the case of our cameras. The slit is punched out of a piece of lead by means of a special hob, which, when pressed further (without withdrawing), cuts a circle out of the lead. Thus the slit is automatically centered in a circular lead disc which may then be fixed at its proper place in the collimator tube.

that of a similar system with 0.75 mm apertures. Compared with the first system, an intensity factor of 3 is gained, when this collimator system is completely filled with radiation.

The value of 0.5 mm was chosen for the aperture widths because it was assumed that in general the specimen would be no thicker than 0.5 mm, and also because this value is well adapted to the focal spot dimensions of the Philips X-ray tubes supplied for use in the Philips diffraction apparatus. A few remarks should be made concerning this latter point.

The collimator system must, on the one hand, insure the beam width and divergence not to exceed the limits set by the desired resolution. On the other hand, it is desired that the radiation of the X-ray tube be used to good efficiency. This evidently will not be the case if the outermost points of the specimen circumference cannot "see" the full projected size of the focal spot because rays coming from the ends of the focal spot are cut off by apertures (cf. fig. 4). Therefore, we might say that the focal spot and the collimator system are well adapted one to the other if the first collimator aperture in fact could be omitted without affecting the beam shape [6]).

With the Philips X-ray tube mentioned above the focal spot is 9 mm long. At an angle of 3° from the face of the anode the projected width of the focal spot is 0.5 mm; in that case, rays from the entire focal spot pass through the apertures of size mentioned above to each point of the specimen cross-section, and the full radiation intensity is utilized. At an angle of 6°, however, which is more commonly used in diffraction apparatus, the projected width of the focal spot will be 0.9 mm, resulting in the ends of the spot not being used. If the 3° angle is always used the only function of the first collimator aperture is to collimate the beam in case an X-ray tube having a larger focal spot than that of the Philips tubes is to be used.

A similar consideration applies to the 2 mm length of the first aperture: the dimensions of the focal spot of Philips X-ray tubes in this direction being on an average only 1.2 mm, the collimating action of the first aperture in this direction likewise becomes apparent only if other tubes, having wider focal spots, are used. With the focus width of 1.2 mm mentioned above, the first aperture is not completely filled by the beam and the intensity gain as compared with two circular 0.5 mm pinholes, therefore, is somewhat smaller than indicated above (gain factor about 2-2$^{1}/_{2}$).

Anti-air-scatter tubes

The deleterious effect of air scatter on the contrast of diffraction patterns can be eliminated by evacuating the camera. This technique, though applied in some cases, is not convenient in instruments for routine investigations. An alternative and much simpler resource consists in confining the primary beam on its path to and from the specimen within two metal tubes (see fig. 2). The entrance tube also contains the collimator system. Film background is reduced because the air path is now limited to the distance between the ends of the two tubes.

As is well known, incorporating the beam collimating system in a tube inside the camera has, moreover, the important advantage that the focus-to-specimen distance can be made smaller, entailing a considerable increase in intensity.

To reduce air scatter to a minimum one would prefer to bring the tubes as close as possible to the specimen. It is obvious, however, that sufficient space must be allowed around the specimen for the emission of the rays diffracted by the specimen. The diffraction lines at angles near 0° and 180° evidently are most liable to be intercepted by the rims of the tubes, and it was quite a common deficiency in cameras previously designed that "blind areas" were caused on the film at these diffraction angles, i.e., around the holes punched in the film at the entrance and exit region for the primary beam. Such a blind area is clearly visible in the pattern of a commercial soap reproduced in *fig. 7b*. On the other hand, fig. 7*a* exhibits the dense background which is produced, particularly near the exit film hole, if no exit tube or one of insufficient length is used.

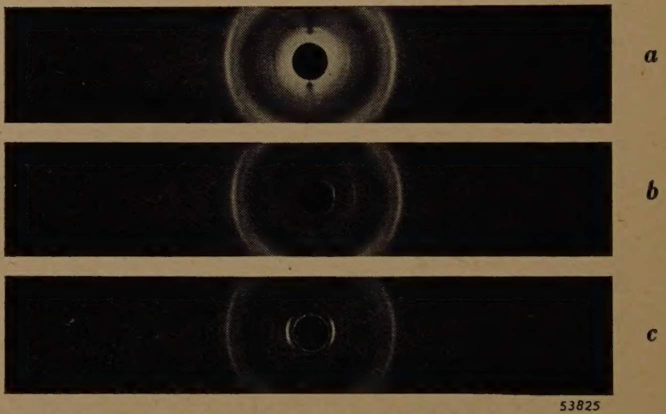

Fig. 7. Part of diffraction pattern of soap, containing the range of diffraction angles 2Φ from 0° to about 90°, taken with copper $K\alpha$ radiation and nickel filter.

a) No exit tube used. Considerable background occurs in the range of low diffraction angles, near 0°.

b) Badly designed exit tube. The tube, due to its contour, intercepts the diffraction lines which would otherwise be registered near the film hole (blind area effect).

c) Recorded with new 114.6 mm Philips camera. Background has been reduced to a minimum, without any blind area effect around the film hole, due to proper design of the collimator and exit tubes. Lines at small angles that could not be seen before are now reproduced very clearly.

Closer investigation shows that it is possible to compute specific dimensions of the anti-air-scatter tubes which give best results for different purposes. These computations have been made for our cameras and the tubes now employed have been designed in accordance with the results. For comparison, a pattern of the same specimen as in fig. 7*a* and *b* recorded with one of our improved cameras is reproduced in fig. 7*c*. The occurrence of a "blind area" outside the film hole is completely avoided; some lines close to the hole, which could not be seen with previous systems on account of either background or blind area, can now be seen very clearly.

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[6]) For a set-up without "first" collimator aperture, cf. A. Guinier, Radiocristallographie, Dunod Paris 1945, p. 80. The same principle is applied also in the Geiger counter spectrometer (cf. footnote[1])).

The line of thought for the computation of the tubes will be outlined below.

Computation of optimum form of anti-air-scatter tubes

Exit tube

Let us take the exit tube first; see *fig. 8*. The diameter of the camera, the diameter of the specimen and the diameter of the film hole are considered as being fixed. The primary X-ray beam — provisionally assumed to have rotational symmetry — is also considered to be given. The simplest form for the exit tube to take will be that of a truncated cone, with the base falling within the film hole while the width and the position of the tip still have to be chosen.

The exit port will, of course, have to receive the whole of the primary beam, whose edge is indicated by line I in fig. 8. The inner rim of the exit port will therefore have to be outside line I, measured from the axis, or rather outside line I', drawn parallel to I in order to provide a certain clearance t, so that the tip of the exit port will not be touched by the beam (otherwise there would be considerable scattering from this tip and the scattered rays would reach the film without hindrance).

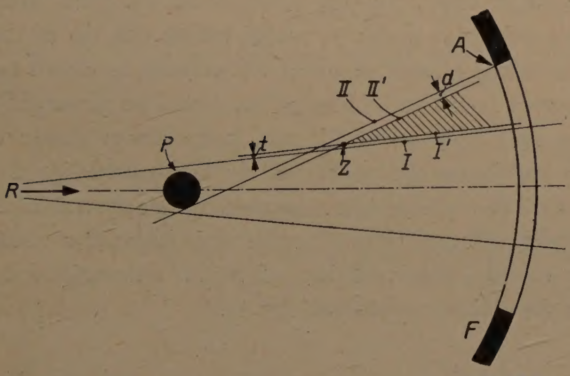

Fig. 8. Dimensioning of the exit tube. *R*, diverging X-ray beam; *P*, specimen; *F*, film; *A*, rim of the exit film hole. For the most favorable design the inner rim of the tip of the exit tube must lie at the point *Z*.

On the other hand, we want to introduce the requirement that the abovementioned blind area effect should be completely eliminated, i.e., that the exit port should not obstruct any rays diffracted from the specimen, not even for the lowest usable diffraction angles. That means that the whole of the specimen must be visible from the rim A of the film hole. The outer rim of the exit port will therefore have to be within line II, and the inner rim within line II' which has been drawn parallel to line II at a distance d equal to the thickness of the wall of the tube.

The two conditions stated above limit the allowable position of the inner rim of the exit port to the hatched region between lines I' and II'. To envelop the primary beam over the greatest possible distance it is necessary to place the inner rim of the exit port in the extreme corner of the hatched area, i.e., at the point Z where the lines I' and II' intersect.

Collimator tube

Similar considerations lead to the required shape of the collimator tube, though here the problem is more intricate, as the collimating of the primary X-ray beam also is involved. We shall provisionally adhere to the supposition that the beam is made rotation-symmetrical, thus that both collimating apertures are circular, their widths, $2s_1$ and $2s_2$ (which need not be equal), being determined in advance on grounds in part explained above. Also it is assumed that the position of the first aperture can be considered fixed on the strength of certain geometrical and physical considerations; we have placed it at a distance $a = 20$ mm in front of the entrance hole in the film. We are still free to choose the position of the second collimating aperture, of course within certain limits.

We can start once again from the fact that the part of the collimator lying inside the camera may be shaped as a truncated cone, with the base falling within the hole punched in the film at the spot where the beam enters the camera. We shall now have to choose the most suitable width and position of the opening at the strip of the tube.

First of all we have to observe that this opening cannot itself be successfully utilized as a second collimating aperture. The primary X-rays are strongly scattered at the edges of the beam-limiting apertures. If the second beam-limiting aperture were to be located at the end of the collimator tube this scattered radiation would reach the film unhindered and that result would be worse than the air scatter it is desired to eliminate. The second collimating aperture must, therefore, be placed inside the collimator tube, and the tube tip (scatter cup), in addition to its function of diminishing air scatter, must keep the rays scattered by the aperture away from the film [7]). Thus we arrive at the configuration sketched qualitatively in *fig. 9*.

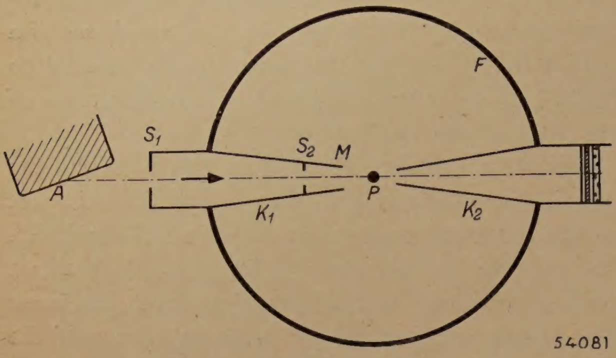

Fig. 9. Configuration of collimator and exit tubes K_1 and K_2 (qualitatively). The second beam-limiting aperture S_2 is inside the collimator tube, so that the rays scattered at this aperture are kept away from the film F by the tube port M (scatter cup). P, specimen, A, anode. (At the end of the exit tube, the three closures mentioned in the description of fig. 2 are indicated schematically.)

From *fig. 10* we can now deduce the conditions which have to be fulfilled by the collimator tube.

The tube tip must not cut off any part of the divergent beam formed by the apertures S_1 and S_2 (for if it did it would itself act as a second aperture). Hence the condition: 1) The inner rim of the scatter cup must be outside line I, measured from the axis, or rather outside line I' drawn parallel to I, again to allow for the necessary clearance t.

Furthermore, the scatter cup must intercept all scattered rays which, coming from the circumference of S_2, would fall outside the film hole on the opposite side of the camera (point A). Consequently: 2) The inner rim of the scatter cup must lie inside line III. The two conditions taken together indicate that the inner rim of the scatter cup must lie in the hatched region shown in fig. 10.

Finally, any blind area in the 180° region outside the entrance film hole must be avoided, which means that it must be possible to see the whole of the specimen unhindered from the rim C of the film hole. Hence it follows that the outer rim of the scatter cup must lie on the inside of line IV, or, if we draw a line IV' parallel to IV at a distance equal to the wall thickness of the tube: 3) The inner rim of the scatter cup must be on the inside of line IV'.

We see that all three conditions together still leave us free to place the rim of the scatter cup somewhere in the triangular part of the hatched field delineated by heavy lines. To envelop the primary beam over the greatest possible length, the rim of the scatter cup will have to be placed in the farthermost right-hand corner (W') of the triangle.

The position and the width of the collimator tube tip are thus fixed as soon as the position of the second collimating aperture S_2, as yet unspecified, has been established. When we vary this position we see that the more nearly horizontal line I (and I') becomes, and thus the smaller the divergence of the X-ray beam, the closer the point W' is brought to the specimen. It is therefore desirable to place the aperture S_2 as close to the specimen as possible. A limit to this is set because, as a closer examination will show, as S_2 is brought nearer to the specimen the apex (W) of the hatched area is shifted in the same direction. S_2 can only be shifted, therefore, until point W has reached the line IV', the delineated triangle in this case being reduced to that single point. The position of the second collimating aperture is then unambiguously established and the largest possible length of the collimator tube corresponds to this situation.

At the same time this position of the second aperture is also the most suitable for the design of the exit tube. In our discussion on this point with reference to fig. 8, which led to the tip of this tube being placed at point Z, we had assumed the primary beam to be limited by line I as given. It is apparent that point Z, too, now comes closer to the specimen the more nearly horizontal line I is made. The permissible lengths of both the collimator tube and the exit tube thus become a maximum when the position of S_2 is determined by the foregoing considerations [8]).

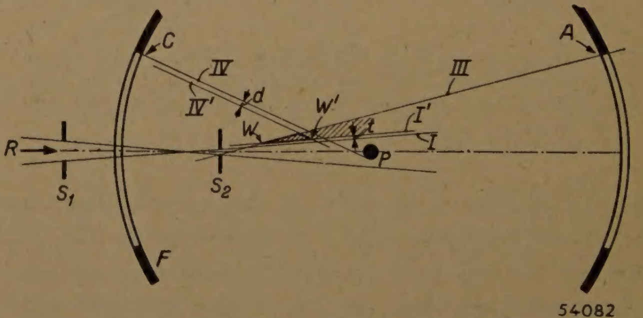

Fig. 10. Dimensioning of the collimator tube. R, X-ray beam; P, specimen; S_1 and S_2, apertures; F, film; C and A, rims of the entrance and exit film holes. With the position of S_2 being chosen arbitrarily as yet, for best results the inner rim of the collimator tube port must lie at the corner W' of the delineated triangle.

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[7] It is a common fault in many camera designs that this requirement is not met. The importance of the requirement was pointed out by M. J. Buerger, l.c. (1945), p. 505.

[8] Incidentally, it should be pointed out that care must be taken to prevent rays scattered back from the wall inside the exit tube from returning through the tube tip and reaching the film. This requirement can easily be met by making this tube conical or by step-drilling it.

The optimum dimensions of the anti-air-scatter tubes can now be computed in an elementary, though not very simple manner, from the criteria established above. We introduce a system of coordinates ξ, η, having its origin O at the center of the entrance film hole as indicated in *fig. 11*. There are five unknowns: u, the ξ-coordinate defining the position of the second collimating aperture S_2; v and w, coordinates of point W, indicating the position and half the width of the collimator tube tip; x and y, coordinates of point Z, indicating the position and half the width of the exit tube tip.

According to elementary principles of analytic geometry we can write the equation for each of the straight lines I'-IV' in the form

$$\frac{\eta-\eta_1}{\xi-\xi_1}=\frac{\eta-\eta_2}{\xi-\xi_2},$$

where ξ_1, η_1 and ξ_2, η_2 are the coordinates of two fixed points through which the line is drawn. Since, according to the above, point W must be situated simultaneously on the lines I', III and IV', we get for the three unknowns u, v, w, the three equations:

$$I': \quad \frac{w+(s_1-t)}{v+a}=\frac{w-(s_2+t)}{v-u},$$

$$III: \quad \frac{w+s_2}{v-u}=\frac{w-f}{v-2R},$$

$$IV': \quad \frac{w+(r+d)}{v-R}=\frac{w-(f-d)}{v}.$$

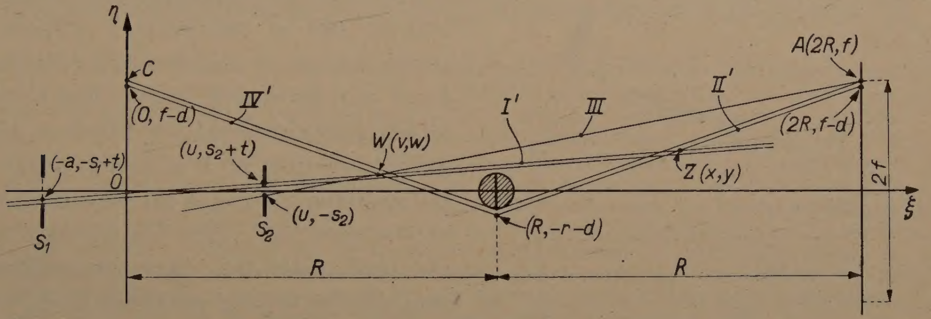

Fig. 11. The position of the second aperture S_2, and that of the points W and Z, indicating the best location and width of the tips of the two tubes, are given in the ξ, η-coordinate system by the coordinates u; v, w; x, y, respectively. The coordinates of all points used for the equations of lines I', II', III and IV' are indicated in the diagram.

Here R is the radius of the camera, r the radius of the specimen, d the wall thickness of the tube, t the desired clearance between the primary beam and the inner rim of the tube tip, f the radius of the entrance and exit hole punched in the film, s_2 half the width of the second collimating aperture; a and s_1 indicate the position and half the width of the first collimating aperture 9). All these symbols stand for known numerical values.

Since point Z lies on the lines I' and II' we derive for the unknowns x and y the equations:

$$I': \quad \frac{y+(s_1-t)}{x+a}=\frac{y-(s_2+t)}{x-u},$$

$$II': \quad \frac{y+(r+d)}{x-R}=\frac{y-(f-d)}{x-2R}.$$

Elimination of u and v from the first three of these equations yields a rather cumbersome quadratic equation for w. After w is known, v and u may readily be computed, and likewise x and y with the help of u. We need not give here the detailed solutions and the computation of the numerical values.

Different types of anti-air-scatter tubes

In the above the rigorous requirement was set that nothing must be lost from the diffraction pattern, that is to say, the whole of the specimen must be visible from the rims of the film holes. In practice, however, this will never be required for the 0° section and the 180° section of the pattern at the same time. Organic compounds which often possess large interplanar spacings and, thereby, will produce very low angle diffraction lines, in general will not yield any "back-reflection" lines (near 180°). Conversely, inorganic compounds ordinarily give distinct back-reflection lines but rarely show lines corresponding to large spacings.

Thus three different cases may be distinguished as regards the desired angle region of the diffraction pattern: the examination of forward diffraction only, of back-reflection only, and general work where neither very large nor very small angles are of interest but an optimal record of the entire "normal" angle region is desired. We have developed a number of different anti-air-scatter tube systems for these various purposes. Some of these are described below, the indicated figures corresponding to the 114.6 mm camera.

The first tube system (No. 77) is calculated for forward diffraction work. The rigorous blind area condition has been applied to the exit tube. Full line intensity is obtained at angles > 4.5° (the minimum angle permitted by the film hole). Lines at angles larger than 90° need not be recorded in

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9) These and the following equations contain two very obvious simplifications (cf. fig. 11): the circular cross-section of the specimen to which lines II and IV should be tangent was replaced by its vertical diameter; and the rim of the two holes in the curved film was assumed to have ξ-coordinates zero and $2R$, respectively. Actual computations showed that the latter simplification is permissible even in the case of the small camera ($2R$ = 57.3 mm) in which the film curvature is greatest.

this case. The collimator tube, therefore, has been extended so as nearly to touch the specimen. This has reduced the non-enveloped length of the primary X-ray beam to 19.9 mm.

An analogous tube system (No. 85) is made for back-reflection work. In this case only the collimator tube is subjected to the rigorous blind area condition, providing full line intensity up to angles of 175.5°. This tube system is used, e.g., for the precision determination of lattice constants. The non-enveloped beam length is 28.8 mm.

For the third case, i.e., all general work as in normal identification of compounds etc., the rigorous blind area condition has been replaced by a less rigorous one for both the collimator and the exit tube. This less rigorous condition consists in setting the requirement that, though not the entire specimen cross-section, at least part of it should be visible from the rim of the film holes. This means that a gradual intensity drop (a kind of "half-shadow") of the outermost lines towards the holes is allowed. *Fig. 12* illustrates the gain in tube length obtainable by substituting this less rigorous condition for the rigorous one. Accordingly, the non-enveloped primary beam path with the third system of tubes (No. 55) has been reduced to 10.9 mm! The air scatter is extraordinarily weak with this tube system. The intensity drop of the diffraction lines as they approach the film holes is noticeable at angles smaller than 6° and greater than 172.5°.

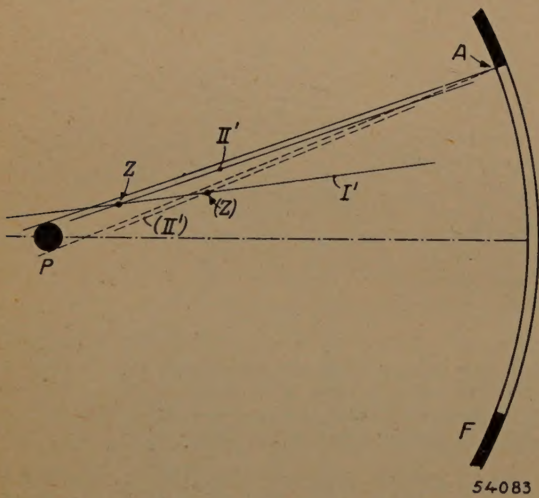

Fig. 12. For the strict requirement made above, viz., that the exit tube tip must not cause any obscuration of the specimen for points outside the film hole (rim *A*), in most practical cases the less strict requirement can be substituted that there should be no complete obscuration while a partial one could be tolerated. The former border line (*II'*) dotted in this diagram may then be replaced by the full line *II'*. The intersection point (*Z*) will come closer to the specimen, at *Z*. The exit tube may, therefore, be longer. Similar considerations apply to the collimator tube.

For cases where high intensity is of prime importance, and a smaller resolution and stronger background are permissible, a similar tube system having a wider second collimating aperture has been designed (0.9 mm; No. 73). The non-enveloped beam length is 30.2 mm for these tubes.

The same five equations as used above hold for the computation of the tubes with the less rigorous blind area condition, the only difference being that $+r$ has to be replaced by $-r$, as may easily be seen from fig. 12.

In the computation of collimator and exit tubes outlined above it was assumed that the X-ray beam has a circular cross-section. Its real shape, however, is oblong (fig. 5). In order to take in this oblong cross-section, a slit-shaped exit port evidently would be best suited. Nevertheless, for practical reasons the exit port, as well as the scatter cup, are made circular in all cases. This means that the exit port in the equatorial plane of the camera is about 3 times wider than is required for taking in the whole width of the primary beam. As a result, in order to prevent the occurrence of a blind region in the equatorial plane, the exit tube tip must be relatively a little farther away from the specimen, and the tube, therefore, has not the full theoretically feasible length. The difference is approximately compensated by the gain in length obtained by changing from the rigorous to the less rigorous blind area condition.

In *fig. 13* a number of patterns are reproduced which were recorded by the 114.6 mm camera, making use of the general purpose type No. 55 (films *a-e*) or of the forward-reflection type (film *f*) of anti-air-scatter tubes. The latter pattern has no blind area around the 0° film hole, the heavy broad diffraction ring in this region corresponding to a lattice plane spacing of ca. 15 Å, but has a large blind area around 180°. (The film of soap, fig. 7*c*, was also obtained with this type of collimator.) In the case of the former patterns (*a-e*), the very small partial blind area around both holes can be seen[10]). All the patterns are remarkable for their low background and their sharp and uniformly blackened lines. The exposure times for these patterns, taken with copper radiation at 45 kV_{peak}, 25 mA, were no longer than 1 to 2 hours, while a good pattern of quartz powder (*b*) could be obtained even with much shorter exposures (10 to 15 minutes).

Finally, it should be mentioned that for studies depending on differences in line shape, e.g., for the measurement of particle size by line broadening, or the examination of preferred orientations of crystallites by non-uniform line blackening, it is desirable to irradiate the specimen only along an axial length about equal to the diameter of the specimen. For this purpose collimators of a more conventional type having two circular pinholes are provided: with a first aperture of, e.g., 0.2 mm and a second one of 0.4 mm diameter, the beam

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[10]) The blind area becomes visible by virtue of the faint residual background of the film which is caused mainly by white radiation diffracted by the specimen.

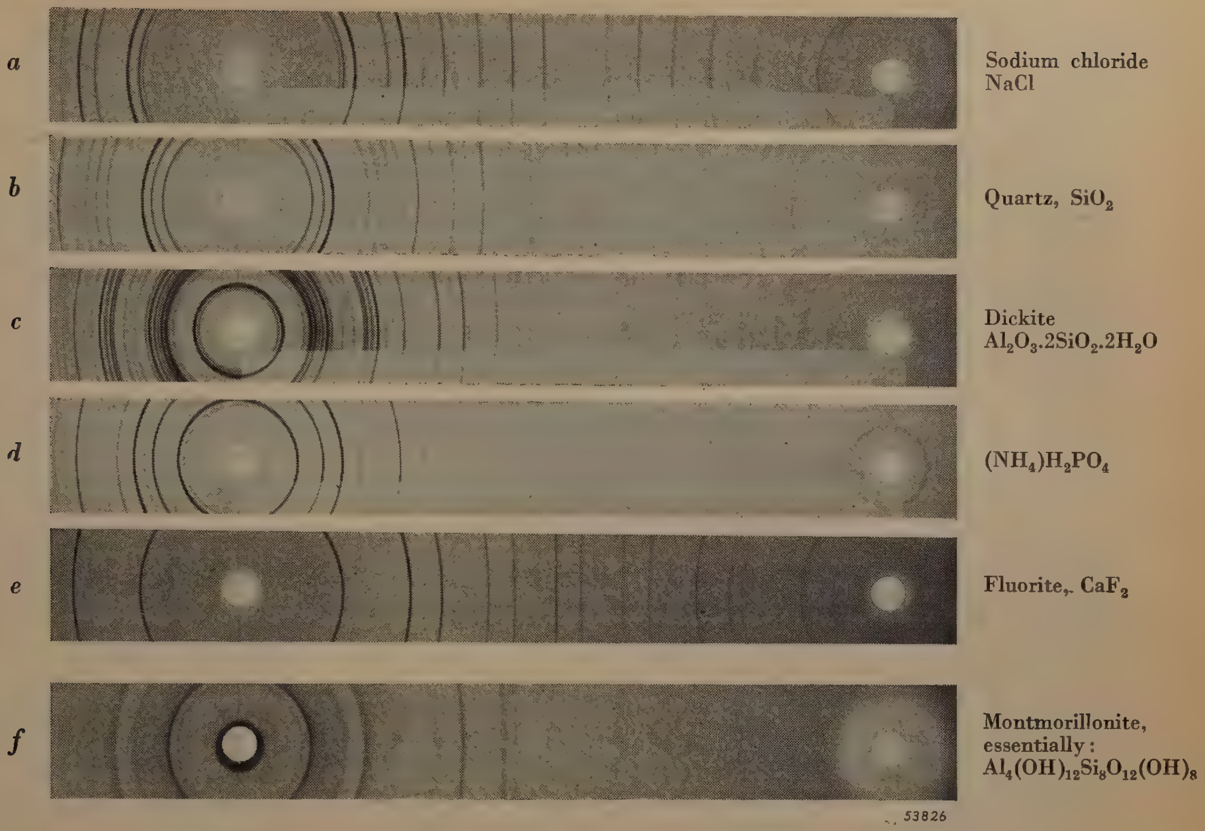
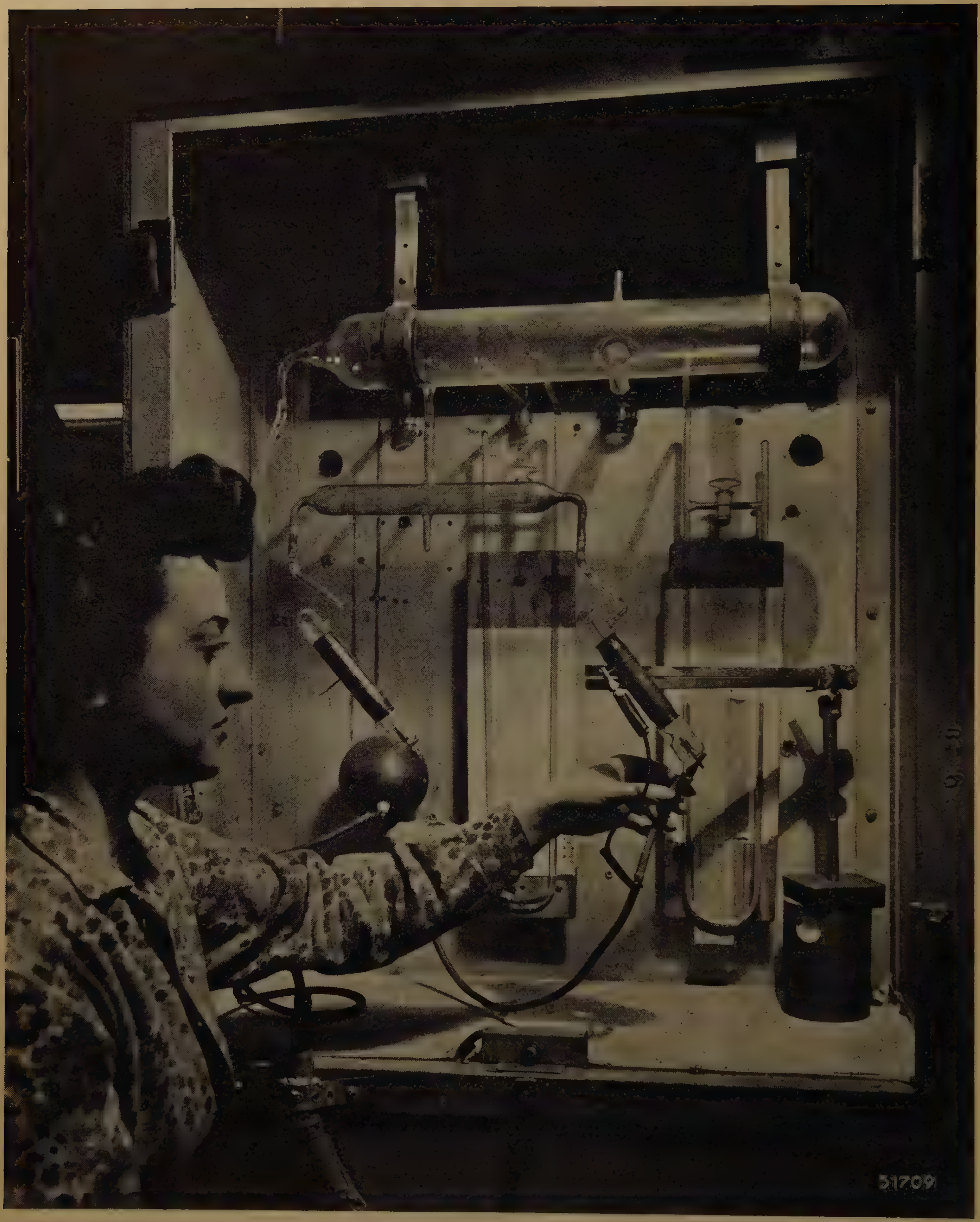


Fig. 13. Six diffraction patterns showing performance of new Philips 114.6 mm camera. All taken with copper radiation at 45 kV_{peak}, 25 mA, with exposure times of 1 to 2 hours; *a*-*e* with general purpose type tube system No. 55 causing small blind areas around film holes, *f* with forward-reflection (only) type causing a large blind area around 180° film hole but no blind area near 0° hole. For films *e* and *f*, a 0.015 mm nickel filter was placed before the window of the X-ray tube, eliminating the undesired copper $K\beta$-radiation so that only the $K\alpha$-diffraction pattern is recorded. For *a*, *c* and *d*, a similar filter sheet covering the lower part of the film was used, so that the major portion of the film represents unfiltered radiation; this technique has the advantage of more rapid exposures combined with easy identification of the undesired $K\beta$-lines. Film *b* was taken with no filter at all. The pattern of fluorite shown in *e* was recorded with black paper being placed over the whole film to prevent the film from being blackened by visible fluorescence caused by the X-rays striking this compound (cf. footnote [4])). In some of the original patterns faint broad diffraction lines are discernible around the 0° film hole; these are caused by a slight devitrification of the Lindemann glass capillary used for mounting the specimen.

(of the 114.6 mm camera) has a width of 0.48 mm at the specimen. Of course intensity is low in this case; it is sacrificed to obtain optimum line shape.

High requirements are set for the precision of the machining in the manufacturing process of the collimator and exit tubes. It may be mentioned, for instance, that the inner diameter of the collimator tube tip must not deviate from the calculated dimensions by more than minus 0 and plus 5 microns. A similar precision is required for the tube fittings in order to insure the necessary exact alignment with the center of the camera. This requirement was made all the more difficult because it had to be combined with an easy interchangeability of the tubes of different types. A practicable solution was found in providing each tube with a precisely machined external surface fitting snugly into a receptacle in the camera wall, while the ultimate positioning on insertion results from matching of very accurately ground faces on the tube collar and the receptacle, these faces being normal to the beam axis.

EXHAUSTING GEIGER COUNTER TUBES



The photograph shows a phase in the manufacturing of Geiger counter tubes in one of Philips' American plants. These tubes, which are used for measuring X-ray or other radiation intensities, are filled with argon or other gases after the air has been exhausted. The gas filling process is checked by connecting the tube to a high voltage source and measuring the number of counts produced with a standard radio-active specimen. Gas ballast reservoirs and manometers for adjusting the pressure of the filling gas to the value desired are seen in the background.

DUPLICATION OF CONCERTS

by R. VERMEULEN.

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By means of electro-acoustic sound equipment, experiments have been carried out in the Concertgebouw at Amsterdam and elsewhere in duplicating the presentation of ordinary concerts in a second auditorium. The equipment incorporates all the latest refinements in the technique of transmission and, in particular, the reproduction is stereophonic, with or without intermediate sound-recording; a new system of noise elimination, not discussed in this paper, enables an exact reproduction of the original dynamics of the music. Experience gained as a result of these experiments and an enquiry made at the time showed that such duplication of concerts provides musical enjoyment much more closely approaching that of the actual concert than what can possibly be had from gramophone or radio reproduction at home. This may ultimately prove a solution to the problem of the overflowing concert halls with which the larger cities are faced and with which they will doubtless have to cope to a still greater extent in the future. A number of features of the results of the experiment are discussed in this paper. In certain respects one might even venture to say that such duplicated concerts are superior to the actual performance. The main apparent point of difference between the actual concert and the reproduction, namely the absence of the visual contact between the audience and the performers, is reviewed from various angles.

Historical development of the concert

For many centuries in the history of the western hemisphere the arts were the exclusive privilege of kings, prelates and aristocrats, who alone were able to afford the luxury of retaining the services of performers in order that they might add to the enjoyment of their palaces the creations of these often very gifted servants. Music, therefore — with the exception of the church — was almost entirely the monopoly of the nobility. In those days an orchestra, whose function was to enchant small and select audiences, consisted of only a few musicians, often grouped around the harpsichord which was played by the conductor himself.

After the time of the French revolution and the American War of Independence, when social leadership was transferred to the people, it was only natural that the latter should also assume the patronage of the arts and so themselves become the audience of the musician. The orchestra thus moved from the exclusive palace chambers to the public concert hall, and this change immediately paved the way to a marked growth, not only in the number of performers, but also in the diversity of their instruments. The wider variety in the timbre of the latter and the increased volume of sound in the larger halls — until then reserved only for renderings of the more specialized sacred music — were eagerly seized upon by composers for the creation of new styles.

It is not necessary to elaborate on the subject of present-day orchestras; one or more concert halls are to be found in all large cities of almost every country, with accommodation for audiences of hundreds, or even thousands: the "Concertgebouw" at Amsterdam seats 2000, the Royal Albert Hall, London, 10,000 and the instrumentalists in such cases will usually number anything from 80 to 120, playing some twenty different instruments.

The question of the moment is the direction in which the development will be likely to progress. Despite the confusion all around us there is a definite tendency to be observed: science continues in the creation of the means to enable ever increasingly larger groups of society as a whole to enjoy a certain prosperity. If such development is not to end in ultimate barbarism, it is however essential that this prosperity shall not be limited to material considerations; people must also be given access to intellectual spheres. To a certain extent literature has already furnished an opportunity of this kind. In the field of music it applies with equal force that this art should be enabled to reach larger and larger audiences, and the situation in which we shall find ourselves in the future and, for that matter, one which here and there exists today, is this, that the large concert halls of the present time will be far too small for the multitudes wishing to attend the concerts.

The problem presented by the masses

Two solutions immediately suggest themselves: the building of more concert halls, or an increase in the size of those to be built. Both solutions involve serious difficulties, however; the first, that is, more concert halls, would mean more orchestras and, even now, the contributions of audiences are usually insufficient to guarantee the performers a reasonable standard of living, rendering subsidies necessary. To draw still larger groups of music-lovers to the concert halls would at first mean that there would have to be a decline in the financial means of the average listener and, at the same time — although of less importance to the point at issue — in his artistic level. With the greater number of orchestras required subsidies would thus have to increase more than proportionally. Another, more fundamental objection is this, that it may be possible, in principle, to duplicate a well-balanced and accomplished orchestra, but not so the personality of the talented exponent. A symptom of this form of check-mate has been met with on many occasions, when a soloist, for example in the Concertgebouw, Amsterdam, has been obliged to give the same performance on two successive evenings. Needless to say, it is only by sheer necessity that a virtuoso is thus called upon to perform on mass-production lines and that this would never be done if there were any possibility of arranging for an audience twice the size to hear the single performance.

This difficulty can of course be met by the second of the above suggestions, i.e. larger concert halls, but here we encounter a financial obstacle; a larger hall will usually demand a larger orchestra, and the number of listeners per musician thus increases only slowly. Again, larger halls increase the element of risk for the producer and, in any case, this solution would come into consideration only in the larger cities; the rural population would not be benefited at all [1]). Finally, it is a very doubtful point whether it would be feasible to give satisfactory musical performances in such very large halls, since certain kinds of music would not lend themselves to such a magnification.

The failure of the most obvious "non-technical" remedies seems to indicate that in this sphere, too, science and in particular that of electro-acoustics must be called in to furnish the means of reaching a larger section of the public.

Gramophone and broadcasting

The conclusion just drawn actually seems to lag somewhat behind the facts, for what else are the gramophone and the radio if not a means for bringing music to the majority? Certainly, both go a long way towards meeting the demand, but in a manner which lacks those essential elements to be found only in the concert hall itself.

Take the case of a gramophone. It offers to the individual the opportunity to hear a particular piece of music most suited to his mood at any given time. It is also obvious that the interpretation of a composition which the individual hears in recorded form is the most perfect it is humanly possible te achieve. On the face of it this would appear to be such an attractive proposition as to render the concerts superfluous, but the facts have disproved this; the development of the gramophone has not reduced concert audiences, but has on the contrary steadily increased them, as witness the very real problem which forms the subject of our discussion. Recorded music, even if representing the limit of perfection in reproduction (ignoring the fact that most of the equipment in present-day use is by no means perfect), has one inherent drawback in the rigidity or monotony which is an unavoidable outcome of the continued repetition of one and the same rendering. In the arts there is no measure of perfection that will satisfy everyone all the time; it is just that progressive recreation, each time with fresh nuances, that keeps art alive.

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[1]) As an example of an effort to solve this problem, we may mention the open-air concerts given regularly since 1928 by the Philharmonic Symphony in the Lewisohn Stadium, New York (15,000 seats).

Radio broadcasting fulfils this need for live, albeit sometimes less perfect, interpretations. It also possesses other important characteristics, amongst others the facility for placing within reach of everyone a great diversity of music at low cost, in which respect it is a unique medium from the point of view of musical education. Even so, there appear to be reasons why broadcast music also lacks the power to rob the concert of its audiences, as borne out not only by the continuance of concerts, but, more especially, by the interest shown in the concerts played before audiences by broadcasting orchestras.

The reason, we think, is not to be sought in the technical imperfections still present in radio reception. Although both gramophone and radio have earned a place for themselves in the field of music, neither the one nor the other in its present popular form is capable of furnishing a solution for the problem that, in principle, reproduction of music in the home just does not satisfy all needs. Even with "technically perfect" reproduction it is undesirable, if not impracticable, to reproduce a concert at the same acoustical level within the confined space of the living room as in the concert hall. The dynamic contrasts which are so essential in the concert hall have to be levelled down in smaller spaces. What is even more important perhaps is the fact that it is often difficult in the home to isolate oneself from all kinds of disturbing influences, whilst, on the other hand, those positive psychological elements to be found in the concert hall itself are entirely absent. The fact that one forms part of an equally-minded community, drawn out of the daily slur of life into surroundings where the sustaining influence of architecture, lighting and acoustics is felt, is just as important in a concert as the effect of the artists personality.

Electro-acoustics in the hall

The conclusion, then, is that the final solution must be sought in the concert hall itself, and the most obvious step is to investigate further the potentialities of the courses of action already outlined above, i.e. more concert halls or larger ones, and to see whether electro-acoustics may possibly assist in removing some of the difficulties described.

By means of electro-acoustics, music can be made to fill larger halls without any augmentation of the orchestra. It is possible not only to employ ordinary amplification methods for the orchestra as a whole, using microphones and loudspeakers, but also to enhance the response of individual instruments in a manner as described in a previous issue of this Review, as applied to the violin [2]), or as universally employed in the electric guitar. It is not felt, however, that the best solution is to be found in this direction, firstly because of the objection raised in an earlier paragraph to the effect that much of our concert music, especially the older compositions, will not lend itself to diffusion in mammoth halls. Secondly, in this form of amplification there is always the danger of acoustic coupling between microphones and loudspeakers which can often only be avoided by adopting less favourable dispositions and characteristics of the microphones. Another factor to be contended with is the difference in time for the contributions from the primary source (the orchestra) and secondary source (the loudspeakers) to reach the audience; in extreme cases this will even produce echos.

The other alternative is more concert halls and here electro-acoustic equipment enables a single orchestra to suffice. The fundamental difficulty that a celebrated soloist cannot be duplicated is disposed of. In the light of present-day technique, *the simultaneous duplication of a concert* in another hall or, if desired, *in a number of halls can be effected to a high degree of musical perfection.* The effects of time lag, mentioned in connection with ordinary local amplification, are then absent, since there is no actual orchestra in the subsidiary hall(s).

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[2]) R. Vermeulen, Perspectives for the development of the violin, Philips Techn. Rev. 5, 40-45, 1940.

The only weak link is the absence of the visual contact between audience and performers, which for some people is an indispensable feature: in the subsidiary hall this contact is of course lacking, although for that matter the position would not be very much better in a concert hall of very large proportions in view of the great distance between the platform and the major part of the accommodation in the auditorium. This point will be referred to later.

Equipment for the duplication of concerts

In order to realize the duplication of concerts, equipment has been built at the Philips Laboratories at Eindhoven, upon every component of which exceptional care has been bestowed, in an endeavour to approach as closely as possible to technical perfection. The aim was to ensure an aural impression in the subsidiary hall which would be as nearly as possible identical to that produced in the primary hall. By reducing to a minimum all imperfections in the reproduction it was ultimately found possible to carry out experiments calculated to put the original idea to the most stringent tests. A brief review of the equipment used, as well as of the results obtained from it, will now be given.

A general impression of the equipment may be obtained from *figs 1* to *3*, the legends of which also give a number of details. The installation is designed for the simultaneous duplication of a concert in one or more concert halls over telephone lines, as well as for subsequent reproduction at any desired time by means of a Philips-Miller sound record. In either case the reproduction is stereophonic [3]). The high and the low notes are reproduced by separate loudspeakers; the channels from the two microphones in the dummy head are separated only for the higher notes. For the low notes the contributions of the two microphones are mixed, since these do not contribute to the stereophonic effect to any great extent. Three output amplifiers are therefore needed and the output from these is on the generous side (60 W each), so that non-linear distortion may be avoided as much as possible. Careful design of all the components of the equipment ensure a flat frequency response characteristic up to 8000 c/s. The microphones used have already been described in a previous issue [4]). The Philips-Miller sound recording unit was made capable of meeting the special requirements by increasing the resonant frequency, this being possible by reason of the fact that the maximum recording amplitude of the double track required for stereophony is only half the normal track width [5]). Finally it may be mentioned that a special and very effective system was employed for the reduction of background noise and other interference to a sufficiently low level to ensure that the full dynamic range of the original performance would be reproduced without the audience being disturbed by the consciousness of the technicalities employed in the system. It is hoped that it will be possible to publish shortly an article in this Review on this important feature of the equipment.

This brief description will have made it clear to the reader that in the system in question many desiderata have been catered for which, for as far as the ordinary reproduction of music by means of radio and gramophone is concerned, still belong to the category of wishful thinking, even in the case of frequency modulation. The introduction of such elaborate devices for the reproduction of music in a hall need by no means be restricted to a model installation such as we had in view here. In considerations affecting reproduction in an auditorium the cost is relatively less important and there is therefore no reason why the equipment as described should not be regarded as a prototype.

The choice of the above mentioned frequency limit of 8000 c/s may need some explanation. In recent years there has been much controversy as to whether frequencies above 4000 or 5000 c/s are really appreciated, or whether the listening public prefer to do without them, even in the original music. From our own experiments we have gained the impression that the ear is particularly sensitive to discrepancies in this frequency range, whether these are to be attributed to non-linear distortion or to deviations from a flat frequency response characteristic. Omission of the sound spectrum above 4000-5000 c/s may be preferable to faulty reproduction, but it cannot be denied that it is just the higher notes that lend

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[3]) A general description of the method employed by Philips in stereophonic reproduction will be found in an article by K. de Boer, Philips Techn. Rev. 5, 112-119, 1940. In the U.S.A. experiments were carried out some time ago, but with stereophony of a somewhat different form: these culminated in the telephonic duplication in a hall in Washington D.C. of a concert conducted by Stokowski in Philadelphia, a description of which appears in Bell System Techn. Journal, 13. 239-308, 1934 (Symposium on wire transmission of symphonic music and its reproduction in auditory perspective).

[4]) A. Rademakers, A condenser microphone suitable for stereophony, Philips Techn. Rev. 9, 330-338, 1947 (No. 11). In this connection see also J. J. Zaalberg van Elst, A low noise level circuit for use with condenser microphones, Philips Techn. Rev. 9, 357-363, 1947 (No. 12).

[5]) Regarding the Philips-Miller sound recorder see A. Th. van Urk. Philips Techn. Rev. 1, 135, 1936. This article also explains why the resonant frequency of the recorder is limited by the maximum amplitude to be recorded (formula 3). The adaption of the Philips-Miller system for stereophonic recording is described in Philips Techn. Rev. 6, 88, 1941 by K. de Boer.

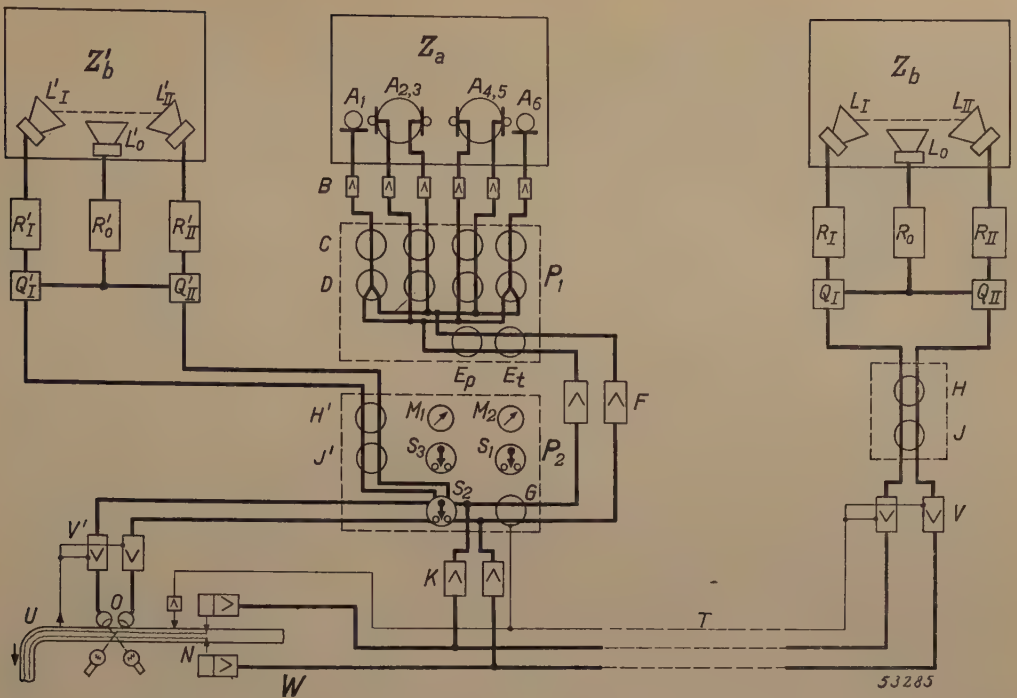

Fig. 1. Block circuit diagram of the equipment built in the Philips Laboratories, Eindhoven for the duplication of concerts. The orchestral music in the concert hall (Z_a) is picked up by a dummy head ($A_{2,3}$) containing two microphones. (In the photograph at the head of this article, showing a rehearsal in progress in the Concertgebouw Amsterdam, this dummy head will be seen suspended above, and just in front of, the platform.) Provision is made also for two microphones (single) (A_1 and A_6) and a second dummy head ($A_{4,5}$), to pick up the performance of soloists, groups of instrumentalists, or a choir. The signals from the 6 microphones are taken by way of 6 pre-amplifiers (B), and cables, to the mixing panel P_1, where the volume and the ratio between the two channels of each stereophonic unit are controlled (controls $D_{2,3}$ and $D_{4,5}$), together with the relative contributions of each of the 4 sources (A) with respect to the two resultant stereophonic channels (controls C, D_1 and D_6). The lower notes can be emphasized in both channels simultaneously (control E_p), whilst the over-all volume is controlled by means of knob E_t. The signals are then passed through intermediate amplifiers (F) to the control panel P_2 and thence by way of line amplifiers (K) either to a telephone line (T) connected to the secondary hall Z_b, or to the Philips-Miller unit W. In the case of direct reproduction in the subsidiary hall the signals are fed to filters Q_I and Q_{II} after re-amplification (V) and adjustment of the volume (control H) and the ratios of the stereophonic channels (control J). These filters separate the high and low registers; the former are taken to the loudspeakers L_I and L_{II} through the output amplifiers R_I and R_{II} and the auditory perspective is produced by disposing these two speakers a suitable distance apart. The low tones in each of the channels are combined, amplified by R_0 and passed to a loudspeaker L_0 which is placed between L_I and L_{II}.

Alternatively, if a phonogram is required, the output signals from the line amplifiers (K) are taken to two Philips-Miller recording units (N) where a stereophonic track is traced on the tape (U). For monitoring purposes, the sound record is reproduced almost immediately in the hall Z_b', the tape passing between the double optical pick-up unit O after leaving the recording heads. The signal thus obtained is amplified by V', readjusted at the control panel (H', J') and then passes through filters and output amplifiers Q' and R' to the loudspeakers L'. The operator, with his two panels P_1 and P_2 in the monitoring hall Z_b' thus hears the immediate result of his mixing and other adjustments.

Potentiometer G on the control panel enables the operator, who has a copy of the musical score before him, to reduce the loud passages and bring up the softer ones, in order to avoid overlooding the amplifiers, either when recording or when transmitting by telephone line, and on the other hand to reduce background noise etc. Although the dynamics of the music are thus compressed, they are subsequently fully restored, since the setting of the potentiometer control is transmitted separately to the subsidiary hall, or is recorded on the sound tape, as the case may be; these signals automatically vary the gain at V (or V' when reproducing from the tape) in the opposite sense as affected by G. The relevant connections are shown as lightly-drawn lines in the diagram.

The control panel also mounts two modulation meters M_1 and M_2 which can be plugged in to different points in the circuit (switch S_1). Switch S_2 enables the monitoring hall Z_b' (Q', R', L') to be connected directly to the signal from the control panel for monitoring in the case of direct line transmission or for comparing the recorded sound with the input signal. Different filters may be connected to switch S_3 for experimental purposes.

life and colour to the music. This, then, was the deciding factor in placing the limit at 8000 c/s; to reproduce higher frequencies does not seem to be worth while as the gain does not compare with the increase in the difficulties to be surmounted, such as background noise and so on.

Experiments and results

After a number of tests at Eindhoven, the equipment was installed in the Concertgebouw, Amsterdam, where a series of concerts given by the orchestra of that name were "duplicated": the main experiments consisted in recording the music and playing this back in an upper hall of the building.

The first of the concerts to be duplicated was conducted by Leopold Stokowski and we had the privilege of submitting for his criticism test sound records made during rehearsals, good use being made of his comments in improving the recording. On another occasion a concert given in the Great Hall of the Concertgebouw under Paul Hindemith was duplicated simultaneously in the Small Hall, to which a number of persons had been invited (14 professional musicians and 27 others), this "audience" being requested to give their opinions on this method of musical reproduction by completing a questionnaire.

Other concerts were similarly duplicated in the studio of Philips Acoustics Dept (E.L.A.) at Eindhoven, the music being transmitted from Amsterdam over a special telephone line, suitable for the transmission of music [6]).

The more important results and experiences arising from these experiments may be summarised as follows.

Almost all who were given the opportunity to listen to these duplicated concerts were agreed that they provide a form of musical entertainment of very much higher value than the reception of ordinary broadcast music and quite comparable in many respects with the original performance; in the questionnaire mentioned above, an enquiry as to the listeners' opinion of the reproduction of the orchestral timbre as such received a "good" from 85%, "moderately good" from 15% only. Stress is laid on the term "as such", since the general question whether it was considered possible to obtain genuine enjoyment from music produced in this manner — not taking as criterion the endeavour faithfully to reproduce the concert — was answered in the affirmative by 95% of the judges.

The effect of perspective produced by the stereophonic reproduction was unanimously considered to be a very great advance. In our own opinion the improvememt is not so much due to the possibility of discrimination between the different directions from which the sounds

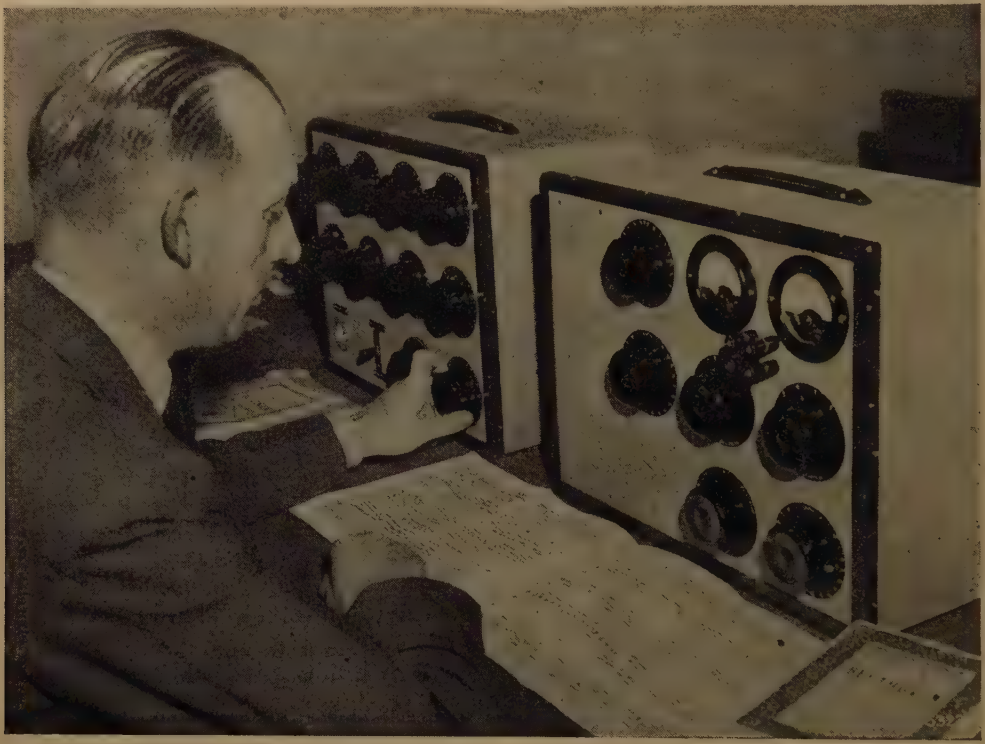

Fig. 2. Mixing and control panel in operation during the recording of a concert. The mixing and „volume compression" is effected with the musical score and the experience gained during rehearsals as a guide. The control knobs referred to in fig. 1 can be easily identified from the photograph: a number of plug sockets will also be seen, these being employed for the connection of different meters, a telephone and a communication microphone (e.g. for speaking to the conductor).

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[6]) We should like to express here our indebtedness to Mr. Stokowski for the interest he showed in the experiments and for the very fruitful discussions we were able to have with him. Our acknowledgements are also due to the Management of the Concertgebouw, the orchestra and, in particular their conductor Eduard van Beinum, for their very willing co-operation. We also tender our thanks to the Post, Telegraph and Telephone Service for the particular care bestowed on the overland connection in the transmission of the Amsterdam concerts to Eindhoven.

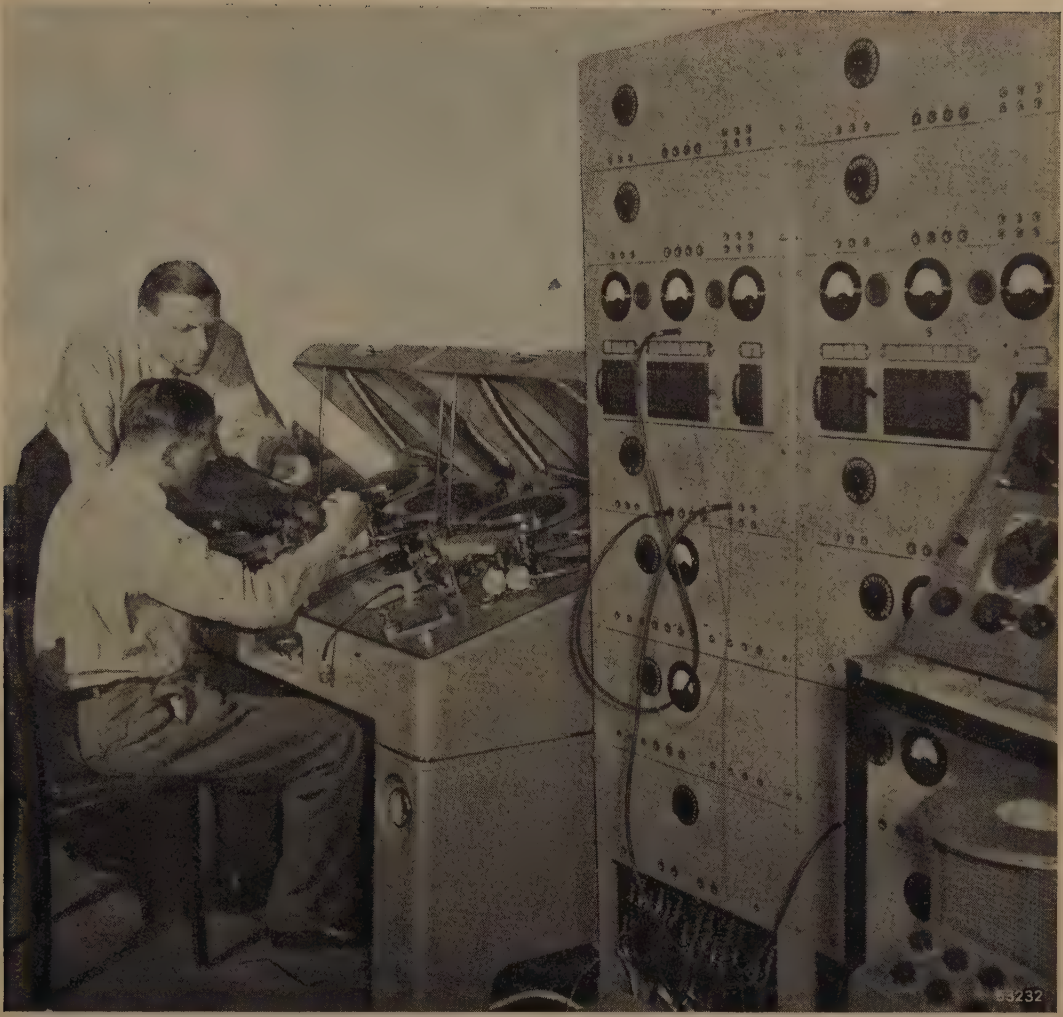

Fig. 3. The Philips-Miller unit, showing some of the amplifier racks etc. installed in the Concertgebouw, Amsterdam.

emanate (or even to follow the sources in the event of their movement), but should be sought more in the facility for picking out the characteristic sounds of the different instruments and the ability to hear the reverberations and possible extraneous sounds as being distinct from the rest.

This was, in fact, borne out by the answers in the questionnaires distributed in the Small Hall of the Concertgebouw, for although, owing to the peculiar unsymmetrical design of the hall, distortion in the stereophonic sound-"picture" at certain points in the hall was unavoidable[7]), nevertheless 95% of the replies attested to the positive value of this auditory perspective.

The impression was gained that the sound level of the reproduction in a given hall is likely to be fairly critical; variations of only 3db from the "most satisfactory" volume appear to have an adverse effect on the general appreciation, though this is of course a question of statistics. In the questionnaire relating to the experiment in the small hall 11% returned the opinion "too loud", 78% gave "good" and 11% "too soft", and from this the conclusion was drawn that the level, by and large, was satisfactory.

Another noteworthy fact is that during the duplication process the engineer at the control panel always has a tendency to bring out the bass notes stronger than they are heard in the actual performance; this was noticed by listening to the concert and the reproduction in turn, and this effect is considered worthy of attention because an exaggeration of the low tones is, in effect, a departure from the primary object, in this case the representation, with the utmost fidelity, of the tone picture as provided by the concert itself. At the same time, this is a peculiarity which is perhaps not unjustifiable from the musical aspect: Stokowski once said "It is one of the greatest shortcomings of the orchestra that the deepest tones are relatively weak and so do not balance the middle and higher tones" [8]). Physically, the explanation of this deficiency is quite simple for, on the one hand, the sensitivity of the human ear is very much lower in the low-note zone than in the range of frequencies from about 1000 to 2000 c/s; on the other hand the radiation resistance for the low tones in the more usual sources of music (apart from organ pipes) is relatively low, owing to their limited dimensions [9]). That the most obvious step, the addition of more bass instruments, does very little to overcome the difficulty will be realised when it is remembered that even doubling of the number of bass players, say from 8 to 16, yields an increase of only 3db in the volume of sound contributed by that section. "Improvements" in orchestral music introduced by electro-acoustics in this respect (and possibly in other directions as well) would seem to suggest future possibitities which, however, the technician will approach only with the greatest diffidence.

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[7]) The hall is oval in shape, with the platform at one end and a small balcony at the other. One of the sides has high windows covered with heavy curtains; the other is recessed, but is acoustically "hard".

The first item in the questionnaire already referred to was the point whether the absence of the orchestra was noticeable as a specific want. Opinions were fairly evenly divided, viz. 39% "Yes" and 41% "No", whilst 10% even considered the absence of the visual element to be an advantage. Of the professional musicians, remarkably enough, only 21 % replied in the affirmative and this seems to indicate that a musical education makes it easier for the individual to concentrate on the auditory impression, whereas it appears desirable for listeners who have received no special musical schooling to have something on which to focus their gaze. For the experiment in the Small Hall of the Concertgebouw the platform was screened by a thin white curtain, behind which the loudspeakers were placed, and a natural resting place for the eyes was therefore lacking; probably one of the most important problems in the duplication of concerts will be just this question of furnishing a suitable visual element that will not, however, distract the attention of the listener from the music. One will obviously expect the solution to come from television, since this is able to transmit a picture of the orchestra to the subsidiary hall, but we ask ourselves whether this would really serve the purpose, for it may be doubted whether the spectacle of a number of toiling musicians is actually the best possible background for the full enjoyment of music. Would it perhaps not be better, now that the opportunity presents itself, to turn this shortcoming to advantage and seek a "better" subject for the eyes to rest upon?

One simple solution which rather circumvents the problem and which would doubtless be considered unacceptable in most circles, is to darken the subsidiary hall. This was tried during the transmission of the concert to Eindhoven and it was generally agreed that in this way the music could be enjoyed to better advantage. Apart from the restfulness to the eyes in their vain roamings, the darkness without a doubt removes the cause of the sub-conscious conflict between the visual and aural impressions. The force of this aural impression is demonstrated by the well-known fact that sightless persons are able fairly accurately to judge the size and nature of a room upon entering it, by the sounds alone. A subsidiary hall will frequently be smaller than the primary one, especially in cases where a notable concert is given in one of the larger cities and duplicated simultaneously in the provinces. If the hall is darkened all visual impressions are removed and a sense of a much larger space prevails, more approaching that of the primary hall, of which the music bears the imprint.

It may be noted here that the acoustical requirements of the subsidiary hall need not conform to such stringent demands as those of the primary hall; in the latter the distribution of sound intensity is governed by numerous reflections from the walls and ceiling and, even in cases where the general acoustics can be considered good, there are inevitably some less satisfactory seats in the auditorium. In the subsidiary hall, however, the loudspeakers can be so disposed as to include the whole audience without any assistance from the walls (provided means of avoiding the visual conflict can be found, the walls are best covered with a good sound-damping material). Every member of the audience will hear the orchestra almost just as clearly as the microphones "hear" it and, as the latter are given the best possible places in the main concert hall, everyone in the subsidiary hall hears the music just as well as, or even better than if he were occupying the best seat. Whether it be for this reason, or possibly on account of the emphasized bass notes, we would not venture to say, but during the experiments remarks were heard stating that certain passages and instruments were more effective in the duplicated concert than in the original.

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[8]) L. Stokowski, "Music for all of us", Simon & Schuster, New York, 1943, p. 189.

[9]) A. Th. van Urk and R. Vermeulen, "The radiation of sound", Philips Techn. Rev. 4, 225-234, 1939.

In conclusion

There is a deep-rooted conviction among many that the arts are so esoteric in character that the technical devices used for bringing them to the masses threaten to bring about a change in art itself. Even supposing this to be true, who can predict whether art would be poisoned and shrivel under the change, or whether on the contrary it will blossom forth anew? The troubadour, who brought the mythology of old as well as of fresh deeds to the knights in their castles certainly lost much of his attraction on the introduction of the printing press, but, even considering the quantity of lower-grade literature disseminated as a result of this invention, one can hardly assert that the letterpress has had a harmful influence on western culture. In the world of music, too, we feel that there is some justification for the hope that fresh technical discoveries will not be obstacles to the attainment of new and unexpected heights: they may even be the means of assisting this upward trend.

The developments described in the foregoing were primarily directed towards the most faithful possible reproduction of the so well known strains of the orchestral concert, and anything beyond this the technician cannot be asked to undertake; it is conceivable, none the less, that these limitations will ultimately be eased, when the artist comes to realise that he can employ these technical devices, which have released the orchestra from its traditional limitations, to create entirely fresh musical impressions.

A FLASH LAMP FOR ILLUMINATING VAPOUR TRACKS IN THE WILSON CLOUD CHAMBER

by N. WARMOLTZ and A. M. C. HELMER *).

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A short description of the Wilson cloud chamber, which figures as an important adjunct in nuclear physical research as well as in investigations into cosmic radiation, is followed by a discussion of the conditions to be met by a flash lamp suitable for the illumination of cloud chamber tracks. A description is then given of a flash lamp specially designed by Philips for this purpose. The latter is an elongated, xenon-filled tube, across which a condenser, charged to several kilovolts, is discharged via a choke. The resultant flash has a duration of a few milliseconds. The lamp is simple in use, with a high efficiency, and the accompanying photographs give some idea of the results to be obtained. Finally, some of the characteristics of the lamp in question are discussed.

Introduction

One of the most important aids to nuclear physical research and the study of cosmic radiation is undoubtedly the cloud chamber, originally constructed in 1910 by C. T. R. Wilson, which has made it possible to render visible and make photographic records of the tracks described by ionised particles such as electrons, mesons and atomic nuclei, through the medium of a gas.

At an even earlier date it had been discovered in the course of laboratory experiments on the formation of clouds in a moist atmosphere, that the condensation of water vapour from super-saturated air takes place mainly on the particles of matter present in the air. Wilson subsequently found that when supersaturation takes place in air which is quite free from solid matter, water droplets are nevertheless formed, in this case on the available free ions. This fact was demonstrated by introducing radio-active materials — which emit high-velocity ionising particles in the form of α or β-rays — into or in the vicinity of the chamber, or by exposing the latter to X-rays or γ-rays.

Proceeding from these discoveries, Wilson developed an apparatus, the cloud chamber, for the demonstration of free ions in a gas by means of the condensation of water vapour which is brought into a state of super-saturation by expanding the gas, thus reducing its temperature. When a high-velocity, charged, particle describes a path through the cloud chamber it produces in that path a train of ions, upon which condensation of the water vapour takes place during the subsequent expansion.

By brightly illuminating this trail of water droplets for a very short space of time, immediately after its production, that is, before the droplets can be displaced by gravity and diffusion, the path of the particles can be photographed and these observations can provide valuable information regarding the nature of the particles in question, as will be explained in the following.

The Wilson cloud chamber has, in fact, yielded very important results; by means of photographs of vapour tracks, Anderson in 1933 discovered the positron, whilst in the same year E. Curie and Joliot were able to observe the so-called materialisation of the photon, in the form of an electron-pair.

In the present article we are concerned mainly with the equipment required for the illumination of the tracks in question and, with this end in view, we shall first look more closely at the construction of the cloud chamber itself.

Details of the cloud chamber

In its modern form, the cloud chamber is an enclosed space having the shape of a flat box, of which the front wall is of glass, the rear wall consisting of a perforated metal plate, usually blackened to avoid the possibility of light reflections (see *fig. 1*). Behind this perforated plate a rubber diaphragm is stretched so as to separate the expansion space from the pressure chamber at the rear. The side wall of the expansion chamber is formed by a ground glass cylinder, or by a metal cylinder provided with a glass window, for lateral illumination.

The whole is rigidly assembled by means of clamps, bolts and gaskets. The pressure side is connected via a reducing valve to a cylinder of compressed air, so adjusted as to place that compartment under a pressure of 2 atm. At that side there is also an outlet valve, normally kept closed by an electromagnet against the pressure within; when the electric current is interrupted the pressure opens the valve, which is very wide, allowing the pressure on this side of the chamber to drop rapidly to 1 atm: when this happens the rubber diaphragm is flexed towards that side and a uniform expansion of the gas in the front chamber takes place.

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*) Physical Laboratory of the Municipal University in Amsterdam.

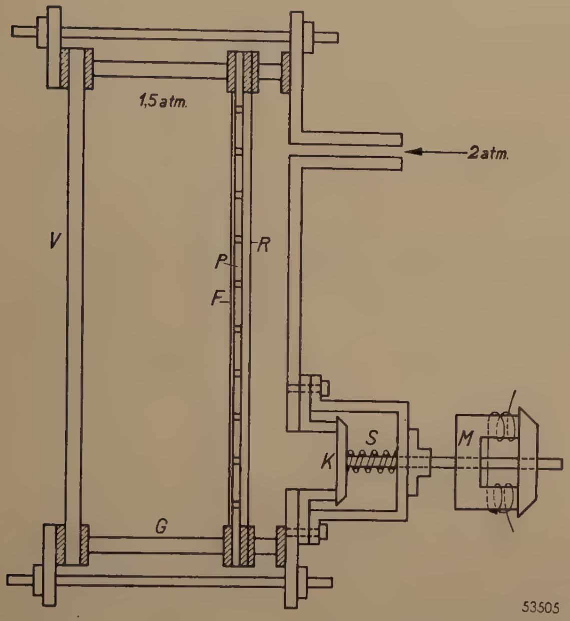

Fig. 1. Sketch of the Wilson cloud chamber in its present-day form. *V* glass front-plate; *G* glass cylinder forming the side wall; *P* perforated metal plate covered in front by a black velvet cloth *F* to prevent reflections of light; *R* rubber diaphragm. The valve *K*, which is held just closed at normal pressure by spring *S* and against higher pressures by the electro-magnet *M*, opens when the electric current is interrupted, thus allowing the gas in the chamber to expand.

The gas in the expansion chamber may for example consist of a mixture of argon and oxygen, at a pressure of about 1.5 atm and saturated with moisture, preferably partly alcohol and partly water vapour. Owing to the presence of the perforated plate, which is, moreover, covered with velvet, expansion within the chamber does not take place too abruptly and turbulences are thus avoided; this is essential since eddies would distort the vapour tracks to a high degree. When the tracks are to be photographed, a lamp producing an intense flash is operated either entirely by electrical means or by contacts on the outlet valve rod shortly after expansion has occurred.

As a result of the adiabatic expansion, a reduction in temperature and consequent super-saturation of the vapour takes place: it has been found that a vapour mixture of alcohol and water (corresponding to a liquid containing 50% alcohol), at an expansion ratio of less than 1.10 produces cloud effects only when the expanding gas is contaminated with particles of solid matter, but that with an expansion ratio of 1.10 to 1.11 droplets are also formed locally on the ions in the gas if it contains no particles of solid matter. Above this ratio of 1.11 arbitrary cloud formation occurs the intensity of which increases as the expansion ratio is increased, and for this reason it is usual to fill the cloud chamber with a gas mixture that is free from all extraneous matter and to employ an expansion ratio of between 1.10 and 1.11.

As already stated, an ionised particle travelling across the chamber leaves in its path a trail of ions: now, if expansion of the gas be made to take place in the ratio specified, shortly after the passage of the particle condensation occurs only on those ions formed along the track of the particle. Using a powerful lateral illumination, it is possible to observe the water droplets and therefore also the particle itself, through the glass front of the chamber. The concentration of the ionisation along the track, as evidenced by the number of droplets per centimetre of track length and the distance travelled by the particle (if the track ends within the chamber) often suffice to draw a conclusion regarding the nature of the particle.

The fact that droplets are formed on the ions at lower saturation values than those required for the appearance of droplets in the absence of ions can be elucidated theoretically.

A droplet of liquid is capable of existence in equilibrium with the surrounding vapour when the vapour pressure in the immediate vicinity is equal to the vapour pressure corresponding to a surface, the radius of curvature of which is *R*; the vapour pressure above a curved surface increases as the radius of curvature is decreased, and so also does the degree of saturation necessary for condensation.

Above a curved and at the same time electrically charged surface, however, the vapour pressure decreases as the radius is diminished below a certain value. For the same value of *R* below that value, the vapour pressure is reduced by the electrical charge and condensation on the ions sets in much more readily than the general condensation arising from the statistic vapour concentration.

When the cloud chamber is placed in a magnetic field of known strength, perpendicular to the front window of the chamber, the momentum of the particle can be determined from the curvature of its trajectory, as produced by the field. The strength of the field used will depend on the anticipated momentum of the particles to be registered, and varies from about 0.02 to 2 Wb/sq.m, which corresponds to 200 to 20,000 gauss.

The Wilson cloud chamber is an extremely useful instrument in the investigation of cosmic radiation and nuclear processes; not only that the curvature of the tracks can be used to determine what particles are liberated on collision of the elementary particles with atomic nuclei of the gas molecules, or with the nuclei of the atoms of absorbent material specially introduced into the cloud chamber, but the resultant transfer of energy or momentum can in many cases also be calculated.

Fig. 2 is an illustration of a well-known example of impact between elementary particles and atomic nuclei: alpha-particles emanating from a radioactive substance shoot through the gas (in this case nitrogen) in the cloud chamber, and one of the tracks visible in the photograph will be seen to terminate in a fork which is produced by the collision of the alpha-particle with a nitrogen nucleus. The long limb of the fork, as may be concluded from the ionisation density and the range, is caused by ejection of a proton, and the short branch by the nucleus which receives momentum at the impact. As no third track is visible, it must be concluded that the α-particle is trapped by the nucleus.

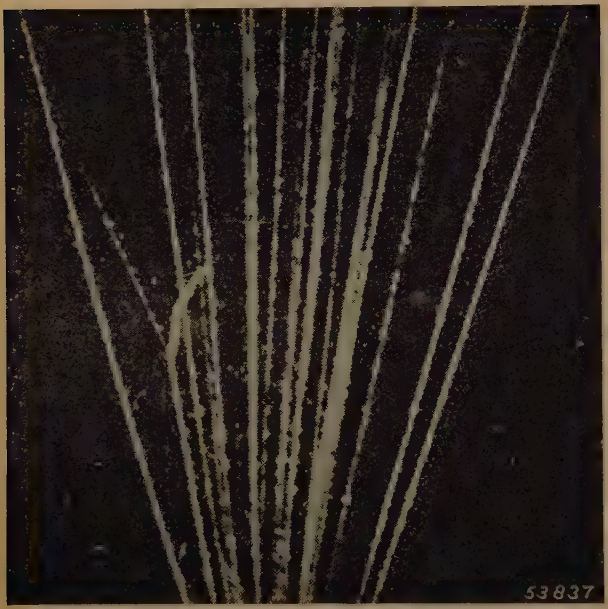

Fig. 2. Cloud chamber photograph showing collision between an alpha-particle and a nitrogen nucleus, causing ejection of a proton and the formation of an oxygen isotope (vide Blackett).

The resultant reaction [1]) may be represented by the formula:

$$_7N^{14} + {}_2He^4 \rightarrow {}_8O^{17} + {}_1H^1.$$

This was the first nuclear reaction to be ascertained: it was observed experimentally by Rutherford in 1919 as the result of the bombardment of nitrogen with α-particles and the result was fully confirmed by Blackett in 1923, using the cloud chamber.

In order that expansion may take place exactly at the correct moment when the cloud chamber is to be used for research on cosmic rays, one Geiger-counter is placed beside the chamber, facing in the direction from which the particles are expected to arrive, and a further counter on the opposite side. These counters produce a small current impulse when an ionising particle passes, which can be amplified as required by means of radio valves. The two counters are so connected that a relay is operated only when both counters are actuated: this means that the particle must pass through both counters as well as through the cloud chamber located between them. The relay operates the magnet of the outlet valve, which then connects the pressure chamber with the outer atmosphere and allows expansion to take place. Naturally, all this must be accomplished in so short a space of time that the ions cannot move too far from the point at which they are originally produced by the particle. Combinations of one or more cloud chambers and a larger number of counters in different positions in relation to each other may be employed for segregating the process to be observed from the many phenomena occurring in cosmic radiation.

This is only one method of employing the cloud chamber. Many other devices are also used to effect the expansion of the gas; in some cases arrangements are made to obtain alternate expansion and compression, preferably at high speeds and without any form of control [2]).

The illumination of the cloud-tracks

The trains of droplets which delineate the track of a particle can be observed only under a powerful form of illumination. Usually the light-source is placed at the side of the chamber to illuminate the droplets through a window or through the glass side wall of the chamber, so that they may be visible from the front by reason of the light which they scatter [3]).

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[1]) W. de Groot, Nuclear Physics, Philips Techn. Rev. 2; 97-102, 1937.

[2]) For a complete review of the applications of cloud chambers, the various processes thereby taking place and methods of measurement, reference should be made to the article by N. N. Das Gupta and S. K. Ghosh in the Review of Modern Physics, 18; 225-290, 1946.

[3]) A method of illumination from a different angle with respect to the direction of observation is discussed in the article by Das Gupta and Ghosh mentioned in note [2]).

Many different illuminating methods will be found described in the literature on the subject under review: Blackett (1934) employed two systems, one of which consisted in discharging a condenser across a narrow mercury vapour discharge tube, whilst in the other these tubes were connected directly to the secondary side of a high tension transformer. The resultant current impulse, of some hundreds of amperes, produces a powerful flash of 0.1 to 0.01 seconds duration. Overloaded incandescent lamps are also sometimes used, 110 V lamps being connected to 220 V mains: yet another method involves the use of continuously burning, super high pressure mercury vapour lamps (e.g. Philips SP 500 or SP 1000), the illumination period being controlled by means of a mechanical shutter.

The main requirements to be met by the illumination are as follows:

1) It should furnish uniform luminous intensity from the side in a drum-shaped chamber. A linear source of light of roughly the same length as the diameter of the drum is very suitable and can be used in conjunction with a cylindrical lens. A screen between the lens and the chamber will prevent light from reaching the front and rear walls and thus producing troublesome reflection.
2) It should produce a high intensity, for a very short period of time. The duration of the flash must be very short, since the diffusion of the water droplets as well as their displacement by the force of gravity tend to widen and distort the vapour track to a considerable extent.

   This latter requirement is particularly important when a large cloud chamber is mounted vertically for the observation of cosmic rays. Since the trajectory of the high-velocity particles, moving in a magnetic field is only very slightly curved, the sagging of the track in a vertical plane might introduce large errors in the determination of the curvature. For this reason the duration of the flash must be less than 10 milliseconds.

   When the chamber is mounted horizontally, as is frequently done for nuclear research, the falling of the droplets does not result in immediate distortion, and longer illumination periods may be employed.

   Nevertheless, the short duration of the flash necessitates very high luminous intensities to ensure sufficient exposure of the photographic plate.
3) The moment at which the flash takes place must be controlled to within an accuracy of about 1 millisecond if the droplets are to be photographed at the most suitable moment after expansion has taken place. A little time may be allowed to permit the droplets to develop, but not too much, in view of the consequent blurring and distortion of the tracks, explained previously.
4) The lighting equipment must not increase the temperature of the cloud chamber, as this also causes distortion due to convection currents in the gas.

A flash lamp for the illumination

The above requirements are all fully covered by a gas-discharge lamp specially designed by us for the purpose; when operated by the discharge of a condenser it gives a flash of short duration.

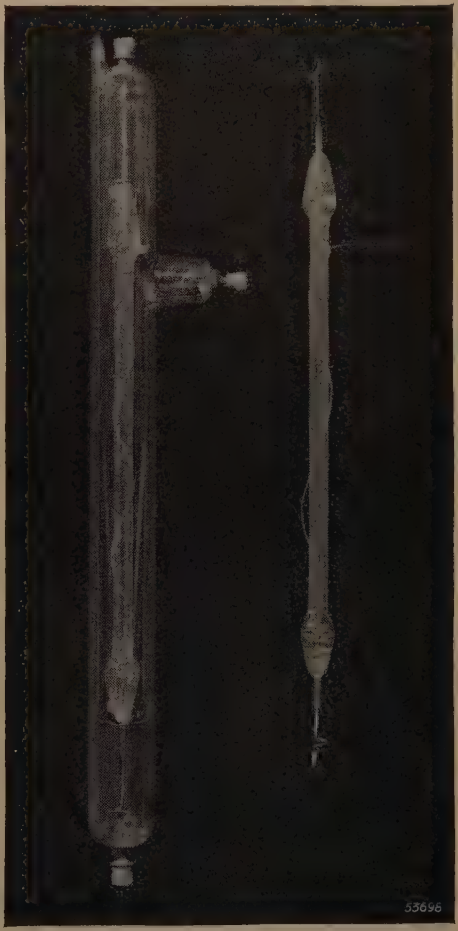

Fig. 3. Photograph of the flash lamp. *a*) the complete lamp, *b*) the flash tube proper.

Fig. 3 is an illustration of the lamp in question: *a*) the complete lamp and *b*) the discharge or flash tube proper, which is mounted in the outer tube to provide a robust, easily-handled unit: the use of this tube or jacket further ensures rigid mounting of the screw-type terminals for the connecting leads.

The discharge tube is made of quartz or glass and has an internal diameter of about 4 mm; the electrode seals and the electrodes themselves, which are both oxide-coated [4]), are accommodated in the widened ends.

If desired the length of the lamp, which is normally about 20 cm, can be adapted to the dimensions of the cloud chamber. The tube is filled with rare gas at a fairly high pressure, the gas used being xenon or krypton to ensure a high luminous output; this point will be dealt with later.

As the window of the cloud chamber is usually made of glass that will not pass ultra-violet rays, the jacket of the lamp is also made of ordinary glass, but for special purposes both discharge tube and jacket can be produced in glass which transmits ultra-violet rays.

The wire coiled round the inner tube serves as ignition electrode. The lamp is operated by the discharge of a condenser, charged to several kilovolts, which is connected to the lamp via a choke in the manner shown in the circuit diagram, *fig. 4*. The choke serves to increase the duration of the discharge, which, without the choke, would be only about 40 microseconds (dependent on the capacitance of the condenser), to several milliseconds, this having the advantage of prolonging the life of the lamp. The inductance of the choke may be 10 mH and the D.C. resistance should preferably be less than 1 Ω.

It has been found that the reduction in the total luminous output of the lamp due to the resistance of the choke in series with it will, in certain instances, have little or no effect on the ultimate blackening of the photographic plate, owing to the decrease in the sensitivity of the latter when the exposure period is reduced. The blackening of the photographic plate is determined by $I.t^p$, in which p is dependent on I and t (I = intensity and t = duration of exposure); in the range under consideration p is usually greater than unity. Consequently, for the same total amount of power input, an increase in the duration of the flash due to the choke may even blacken the plate to a greater extent, notwithstanding the reduced total emission of light.

The lamp just described is not only used as an adjunct to the cloud chamber, but it has a very wide range of application for photographing phenomena of very short duration in other fields as well. In such cases the choke can be omitted without detriment to the flash tube, provided the amount of power applied per impulse is reduced.

Ignition is established by a voltage impulse of about 10 kV, furnished by a low-power impulse generator: a condenser charged to 300 V and discharged through the primary winding of a transformer will serve the purpose. The high tension side is then connected directly to the ignition electrode.

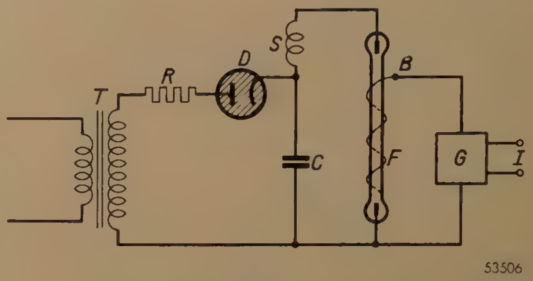

Fig. 4. Diagram of the flash lamp circuit. The condenser *C*, the value of which may be between 10 and 100 μF, is charged to the extent of several kilovolts by the transformer *T* and diode *D*, across a resistor *R*. An impulse delivered by the generator *G* and applied to the external electrode *B* provides a weak discharge in the flash lamp *F*, in consequence of which the condenser *C* discharges through the choke *S*. The resultant brilliant flash has a duration of a few milliseconds. The generator *G* is operated by applying a low voltage impulse to the terminals *I*; this impulse is produced either wholly electrically or partly mechanically when expansion takes place in the cloud chamber.

A very serviceable impulse generator may be provided by a radio valve with a choke in the anode circuit. The valve is so arranged as to pass a steady anode current at rest, the required voltage impulse across the choke being produced by suddenly rendering the grid negative.

Results

Using a cloud chamber such as the one described in an earlier paragraph, in combination with the flash lamp under review, photographs have been taken of the tracks produced by cosmic rays, and these are reproduced in *figs 5* and *6*. The chamber was mounted vertically and the light from the lamp was concentrated by means of a cylindrical lens (glass tube filled with water).

Fig 5*a* depicts the track of a high-velocity electron or meson which has liberated a low-velocity electron by collision with a nucleus in the gas; owing to its lower velocity, this describes a more or less arbitrarily curved path. In fig. 5*b* a portion of a track is shown greatly magnified. Fig 6 shows what is probably a particle of the cosmic radiation (possibly a photon) liberating an electron and a meson, in the upper part of the cloud chamber; the meson has in turn produced a secondary particle, possibly an electron, but more probably another meson.

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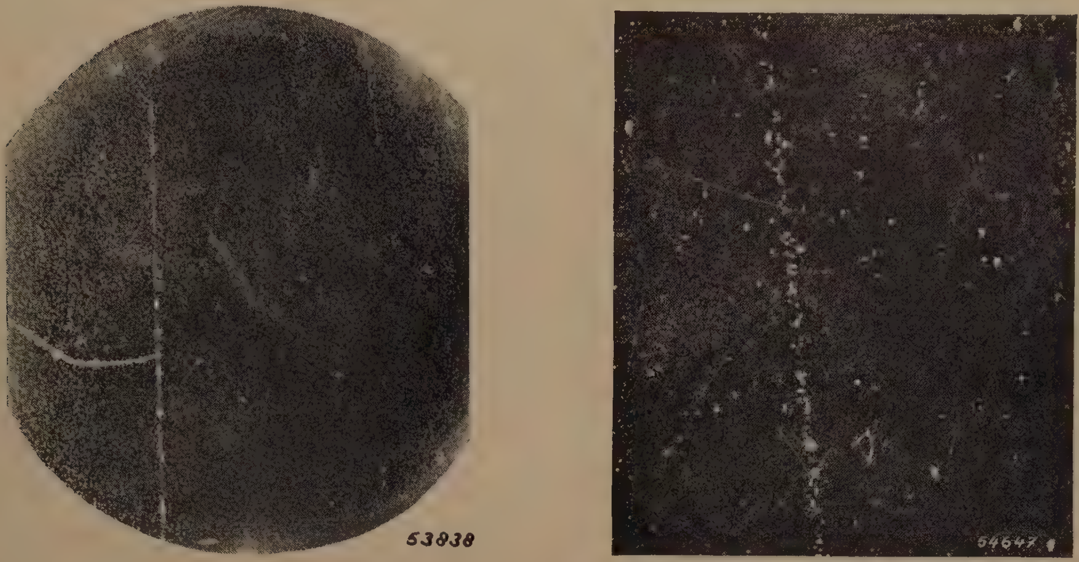
[4]) As both electrodes are oxide-coated, the direction of the current may be reversed when that electrode which is first used as cathode deteriorates in use; in this way the life of the lamp may be prolonged.

As will be seen from these reproductions, the tracks of the high-velocity particles can be faithfully recorded by means of the equipment with which we are concerned.

The exposures, which were about 2 milliseconds, were made 0.25 seconds after expansion of the gas in the chamber. The condenser was discharged through a choke of 0.7 mH having a D.C. resistance of 0.02 Ω and the camera used was a Contax, stopped down to f/5.6; the film used being Ilford HP 3.



a *b*

Fig. 5. Photographs of cloud chamber tracks taken with the aid of the flash lamp described above. *a*) High-velocity electron or meson colliding with a nucleus and liberating a low-velocity electron, the track of which is curved; *b*) Portion of a track greatly enlarged. These photographs and the next one have in no way been retouched. In the background a number of droplets will be seen which have condensed on particles of dust; it is essential that the definition of the tracks is such that the droplets can always be distinguished and counted under an ordinary magnifying glass.

Fig. 6. Another example of a vapour track as photographed with the Philips flash lamp. This shows, in the upper portion of the chamber, a cosmic ray particle (possibly a photon) liberating an electron and a meson, producing in turn a secondary particle, possibly an electron, but more probably another meson.

The load on the flash lamp represented 320 wattsec as produced by the discharge from a 40 μF condenser, previously charged to 4 kV 5)).

The flash lamp itself, 20 cm in length, is found to have an effective life of more than 100,000 flashes, of an input of 500 wattsec, and at a rate of 8 flashes per minute; even at loads of 1000 wattsec the life is quite good, so that, if higher intensities are required for photographing less clearly defined tracks, or to permit of smaller lens apertures, higher loads may be safely applied to the flash lamp. It is of course also possible to employ two lamps, one each side of the cloud chamber, whilst if the latter is made with a glass cylinder as side wall the use

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5) The light was radiated freely all round, only a part of it being effectively used. It is also possible, however, to apply a specular coating to the rear wall of the lamp and thus also to utilise the flux emitted at ths side.

of an annular lamp placed round the chamber offers considerable advantage.

Since the flash lamp functions without warming up (unlike some other types of light source) and as a single flash develops very little heat, there is no risk of convection currents being produced in the gas (requirement 4).

It has been shown, then, that the flash lamp fully meets the four conditions specified above, but it also possesses other favourable characteristics, namely:

a) since the lamp does not burn continuously, no screens or mechanical shutters are required;

b) the simple method of ignition dispenses with the necessity for relays and permits of the design of light, non-arcing apparatus, this being of particular advantage in cosmic ray research by means of aircraft;

c) the running costs are extremely low, since the power consumed is only that taken by the flash; no pre-heating is required, as in the case of mercury lamps.

Some characteristics of the flash lamp

Finally, let us look more closely at some of the properties of this flash lamp [6]).

It has already been stated that a rare gas is used for the filling the lamp, usually xenon or krypton, or a mixture of two or more such gases. The question which kind of gas gives the best results can be answered by means of *fig. 7*, in which the horizontal co-ordinate shows the voltage in kV to which a 100 μF condenser was charged to operate the flash-lamp. The vertical axis gives the total quantity of light from a single flash in arbitrary units.

These tests were carried out with the aid of a potassium photocell of the vacuum type, provided with filters to ensure an approximation of the sensitivity to the relative luminosity curve, in conjunction with a ballistic galvanometer.

The distance between the photocell and the light-source was varied to ensure that no saturation of the electron current occurred at the very high luminous intensities concerned. No saturation was found to take place at sufficiently high anode voltages (about 400 V), and the deflection of the galvanometer was therefore directly proportional to the total quantity of light emitted during the flash.

It will be observed from this figure that the heavier rare gases give a much greater quantity of light than the lighter ones, for which reason xenon is obviously the best medium for the filling of flash lamps; the measurements discussed in the following are therefore all based on the xenon-filled lamp.

A large portion of the light produced by the xenon-filled flash lamp comprises a continuous spectrum, similar to that of a black body at about 6000 °K, which means that the light is practically white. The sprectrum extends into the ultra-violet zone and a marked group of xenon lines also appears at the infra-red end; in the visible part of the spectrum some xenon lines are superimposed on the continuous spectrum. Specific absorption in the tube is found to be only very slight or entirely absent.

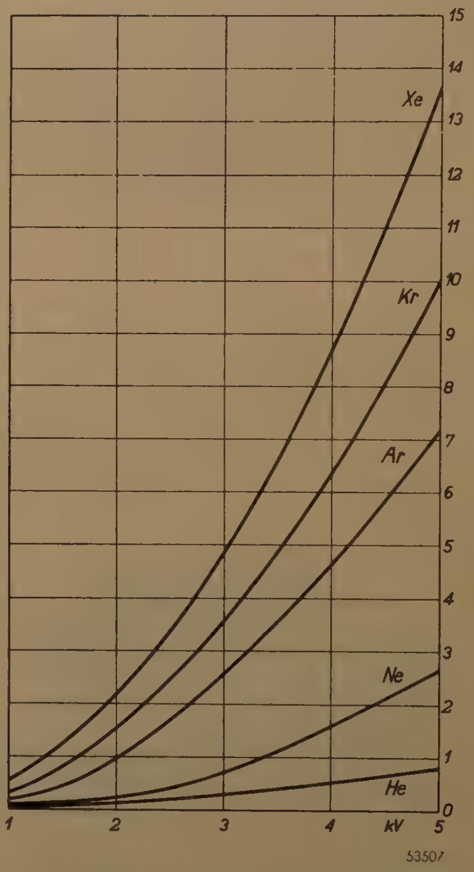

Fig. 7. Total visible quantity of light of a single flash (in arbitrary units), as a function of the voltage across a condenser of 100 μF, for helium, neon, argon, krypton and xenon (at the same pressure), as measured with a ballistic galvanometer and a photocell matched to the relative luminosity curve.

Tests were further carried out to ascertain what effect the gas pressure has on the quantity of light produced, and it was found that the latter increases steeply with the pressure (see *fig. 8*). *Fig. 9* illustrates the total quantity of visible light as a function of the applied power using a condenser of 100 μF; it will be seen that the efficiency at 400 wattsec without a choke is 42.5 lumen/watt, and 29.5 lumen/watt with an inductance of 7 mH and 1.1 Ω resistance in series with the lamp. The measurements were carried out with a standard type of condenser, not specially designed for low inductance and resistance values.

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[6]) For a description of a rather different type of flash lamp, developed for another purpose, see S. L. de Bruin: Apparatus for stroboscopic observations. Philips Techn. Rev. 8, 25-32, 1946.

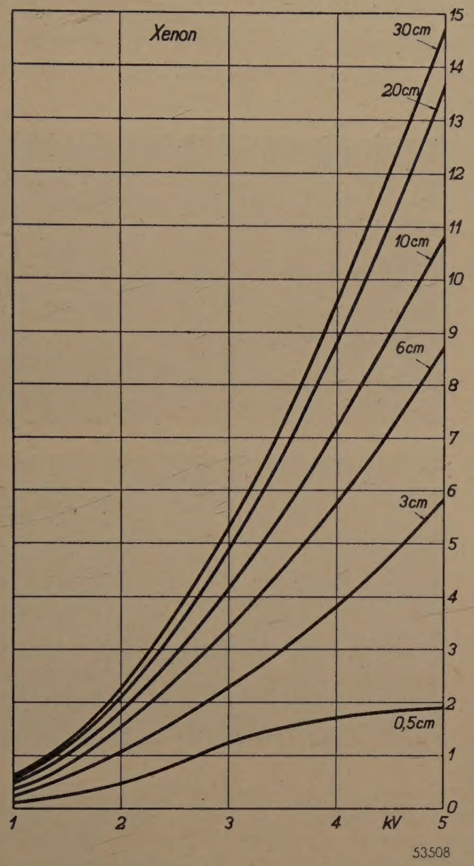

Fig. 8. Total visible quantity of light of the flash lamp (in arbitrary units), as a function of the condenser voltage, for xenon at different pressures.

In order to investigate the development of the discharge as a function of the time, measurements have also been made of the current, the voltage and the total quantity of light by means of a cathode ray oscillograph ⁷). Figs *10a, b* and *c* are the reproductions of the oscillograms as taken without a choke in the circuit. Fig. 10*a* shows the current through the flash lamps, using a 20 μF condenser at a potential of 2 kV. With the object of determining the duration of the discharge, a sinusoidal voltage of a known frequency was photographed on the same plate. It was found that the current drops to one half of its peak value in 4×10^{-5} seconds; fig. 10*b* depicts the corresponding voltage on the lamp. The oscillogram in fig. 10*c* shows the variation in the total quantity of light emitted; in this case the difference in potential was taken across a resistor of 470 Ω connected in series with the above-mentioned photocell and passed to the oscillograph after having been amplified. The luminous intensity will also be seen to decrease to one half of its maximum after 4×10^{-5} seconds.

Let us now look at some of the results obtained with a choke in series with the flash lamp which are represented by *fig. 11*. Fig. 11*a* refers to the current; an initial positive flow of current lasting 1.2×10^{-3} sec is followed by a further wave in the opposite direction ⁸). Fig 11*b* shows the fluctation in the light emission, of which the initial wave also covers 1.2×10^{-3} sec; the second wave is produced by the current flowing in opposite direction.

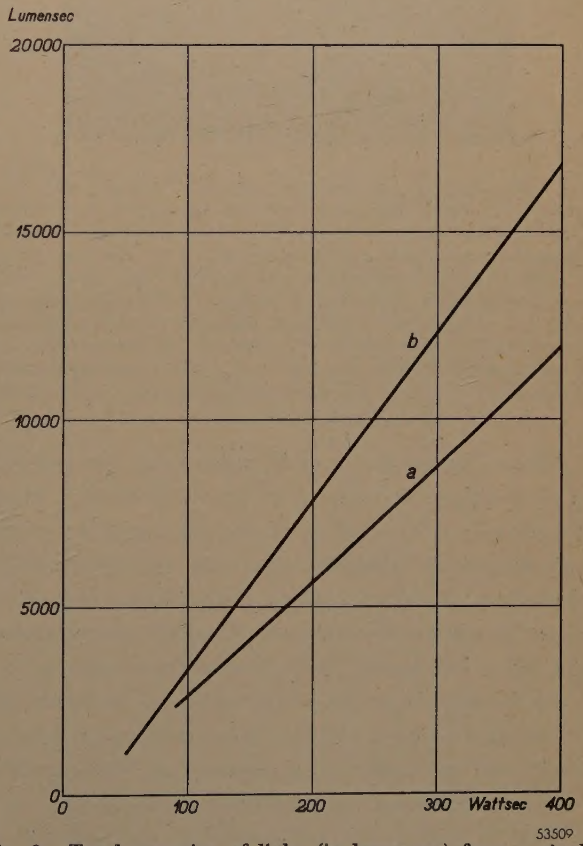

Fig. 9. Total quantity of light (in lumensec) from a single flash of a xenon-filled flash lamp as a function of the applied power, using a 100 μF condenser: *a*) with choke, *b*) without choke.

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⁷) A description of the circuit used in this case is given in an article by N. Warmoltz, The ignition mechanism of relay tubes with dielectric igniter, Philips Techn. Rev. **9**, 105-113, 1947 (No. 4), see fig. 6. As is customary, the electron beam was suppressed during the inoperative period, the photograph being taken from the screen of the cathode-ray tube which has an acceleration of 5 kV, with a single sweep time base.

⁸) It is therefore advantageous when the choke is included in the circuit to employ a flash lamp in which both the electrodes are oxide-coated.

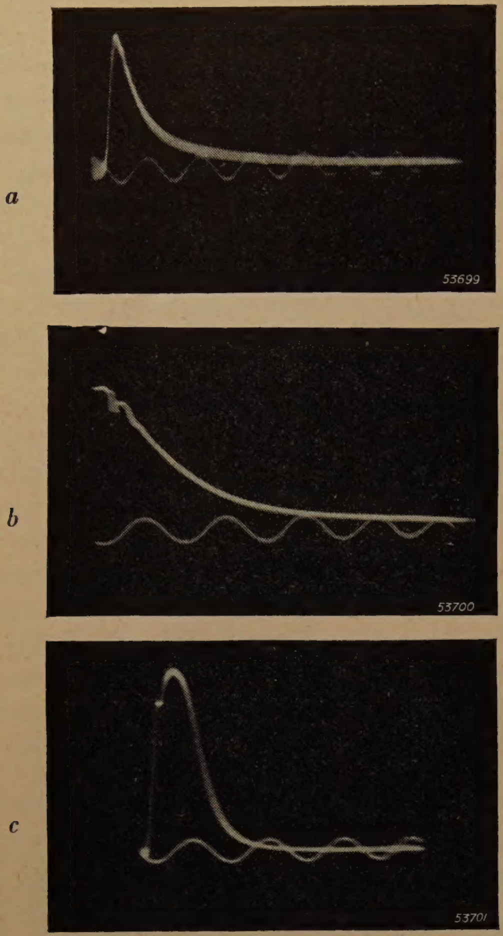

Fig. 10. Oscillogram showing current, voltage and total quantity of light during one flash (without choke): *a*) current curve with a condenser of 20 μF at a potential of 2 kV. The calibrating frequency is 15,000 c/s. At 4×10^{-5} sec the current is seen to have dropped to one half of the peak value. *b*) Corresponding variation in voltage: calibrating frequency 5000 c/s. *c*) Quantity of light (at the same voltage and capacitance). Calibrating frequency 15,000 c/s. As the emission also drops at one half of the maximum in 4×10^{-5} sec, the duration of the flash is almost the same as that of the current pulse.

When the choke is used, either for the purpose of prolonging the flash or to preserve the life of the lamp, it is advisable to keep the resistance of the coil as low as possible, since the inclusion of the choke has an adverse effect on the efficiency of the lamp, as will be seen from fig. 9 which demonstrates the lamp efficiency, with and without choke.

To obtain some idea of the value to be attributed to the choke which will not reduce the efficiency too much, let us turn for a moment to the question of the "resistance" of the flash lamp itself.

Fig. 12 shows the behaviour of the voltage on the lamp as a function of the current passing during one flash. The slope of the curve with respect to the horizontal is a measure of the lamp resistance.

The oscillogram commences at a point on the vertical co-ordinate (just visible in the photograph as a small spot). In the first moments the current increases rapidly, whilst the voltage decreases only slowly; owing to the high speed at which the whole process takes place the first branch of the curve (except the initial point to which we have just referred) is not visible in the oscillogram. From the second part of the curve it appears that the resistance increases with the time.

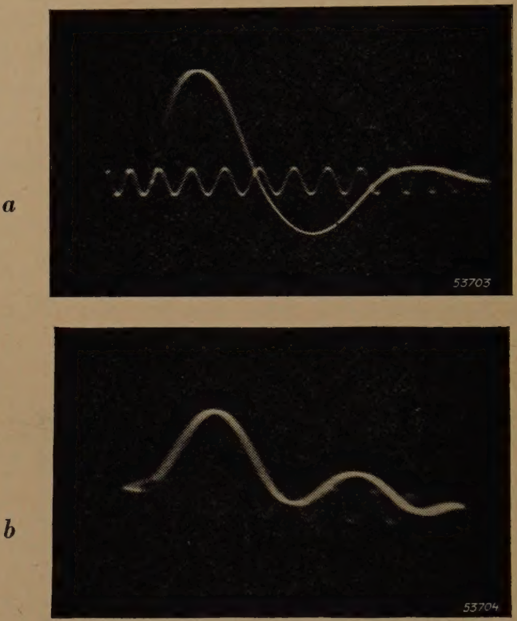

Fig. 11. Current and quantity of light as a function of time, a choke being connected in series with the flash lamp. For this measurement a choke having a self-inductance of 7 millihenry and a resistance of 1.1 ohm was used. *a*) Current as a function of time. The voltage was, once again, 2 kV and the condenser had a value of 20 μF. The calibration frequency was 2500 c/s. The duration of the first positive current wave is 1.2×10^{-3} sec. *b*) The quantity of light as a function of time.

The resistance is actually quite low, being 2 to 3 Ω at the moment when the current reaches its maximum value and increasing to about 6 Ω as the

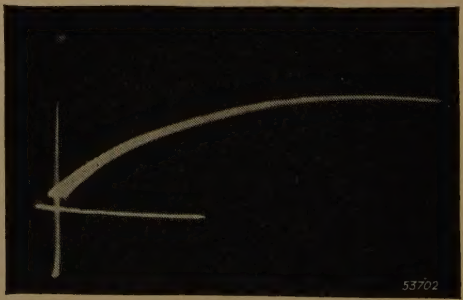

Fig. 12. Oscillogram illustrating the effective resistance of the flash lamp versus the time. The deflection along the horizontal axis is proportional to the current, and that along the vertical co-ordinate is proportional to the voltage; the slope of the curve with respect to the horizontal is thus a measure of the resistance of the lamp. For this test a potential of 4 kV was used, the condenser in question being 100 μF. If actual values are required, the different horizontal and vertical sensitivities must be taken into account.

current drops. The resistance of the choke, then, must be low in comparison with these values.

The measurements just described were effected with a xenon-filled lamp 20 cm in length, but experiments with other fillings and different lengths of tube have proved that both these factors will considerably affect the results of the measurements. If so desired, even shorter flash periods can be attained by a suitable selection of the physical dimensions and gas fillings of a lamp of this type.

If a flash lamp is to be employed on higher voltages than those which can be withstood by the lamp without breaking down (without ignition impulse), a relay tube that can withstand the higher potential may be placed in series with the lamp and this may be fitted with a mercury cathode capable of emitting the high peak currents 9). The loss in energy due to inclusion of this tube does not exceed a few per cent.

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9) A relay tube of this kind with a dielectric igniter is described in the article referred to in note 7), and the tube in combination with a flash lamp in the article indicated in note 6).

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATION OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

Reprints of these papers not marked with an asterisk can be obtained free of charge upon application to the Administration of the Research Laboratory, Kastanjelaan, Eindhoven, Nederlands.

R73: B. D. H. **Tellegen**: The gyrator, a new electric network element (Philips Res. Rep. 3, 81-101, 1948, No. 2).

Besides the capacitor, the resistor, the inductor and the ideal transformer a fifth, linear, constant, passive network element is conceivable which violates the reciprocity relation. This element is a four-pole in which the secondary current and voltage are proportional to the primary voltage and current respectively; it is denoted by the name of "ideal gyrator". By its introduction the system of network elements is completed and network synthesis is much simplified. The gyrator can be realized by means of a medium consisting of particles carrying both permanent electric and permanent magnetic dipoles or by means of a gyromagnetic effect of a ferromagnetic medium.

R74: H. **Bremmer**: On the theory of spherically symmetric inhomogeneous wave guides, in connection with tropospheric radio propagation and under-water acoustic propagation (Philips Res. Rep. 3, 102-120, 1948, No. 2).

The conception of the atmposphere as a curved wave guide consisting of an inhomogeneous medium, through which radio waves and acoustic waves can be propagated, is worked out. The guiding effect is compared with that occuring in the propagation of acoustic waves through oceans. The properties of these two types of spherical wave guides are in many respects interrelated, but there are some essential differences which are brought to the fore. These differences are due to the fact that the product $r\mu$ (r = distance to the centre of the earth, μ = index of refraction) shows at least one minimum in the case of atmospheric propagation and one maximum in the case of oceanic propagation. As a consequence there is a difference, for instance, in the distribution of the times of arrival of consecutive rays orginating from a point source: in the first case the intervals between these times are smallest for the rays coming latest, in the second case they are smallest for the rays arriving earliest.

Some general remarks are made with respect to arbitrary spherically symmetric wave guides. For example, the concept of cut-off frequency is discussed from the point of view of the modes as well as from that of geometric optics.

R75: A. **van der Ziel** and A. **Versnel**: Measurements of noise-factors of pentodes at 7.25 m wavelength (Philips Res. Rep. 3, 121-129, 1948, No. 2).

Measurements are given of noise factors of pentodes at 7.25 m wavelength as a function of the transformed antenna resistance, and the results are compared with the theory. Theoretically, induced grid noise might be partly suppressed by inserting a small resistor of e.g. 30 Ω in the cathode lead. This should reduce the noise factor, but in practice other effects cancel this reduction. It is shown that in many cases the selfinductance of the cathode lead increases the noise factor, but this may be counteracted by inserting a capacitor in the cathode lead, so that series resonance is obtained. Finally, the influence of internal feedback is investigated, and it is shown that it may give rise to an increase of the noise factor.

R76: K. F. **Niessen**: Indication of landing courses independent of weather conditions, II and III. (Philips Res. Rep. 3, 130-139, 1948, No. 2).

This is a continuation of the theory given in **R66** (see these abstracts). In II and III the case is considered where the infinitesimal dipoles are replaced by antennae of final length, the landing course being indicated by antennae placed at different heights (II) or at equal heights (III).

R77: J. M. **van Hofweegen** and K. S. **Knol** A universal adjustable transformer for u.h.f. work (Philips Res. Rep. 3, 140-155, 1948, no. 2.

A matching device for u.h.f. work is described with which any impedance can be matched to any other impedance by properly adjusting two shorting bridges. It consists of a screened two-wire Lecher system assymetrically loaded with respect to the screen. The device can also be used for coarse impedance measurements. Based on the same principle, a universal adjustable transformer using wave guides can also be made.